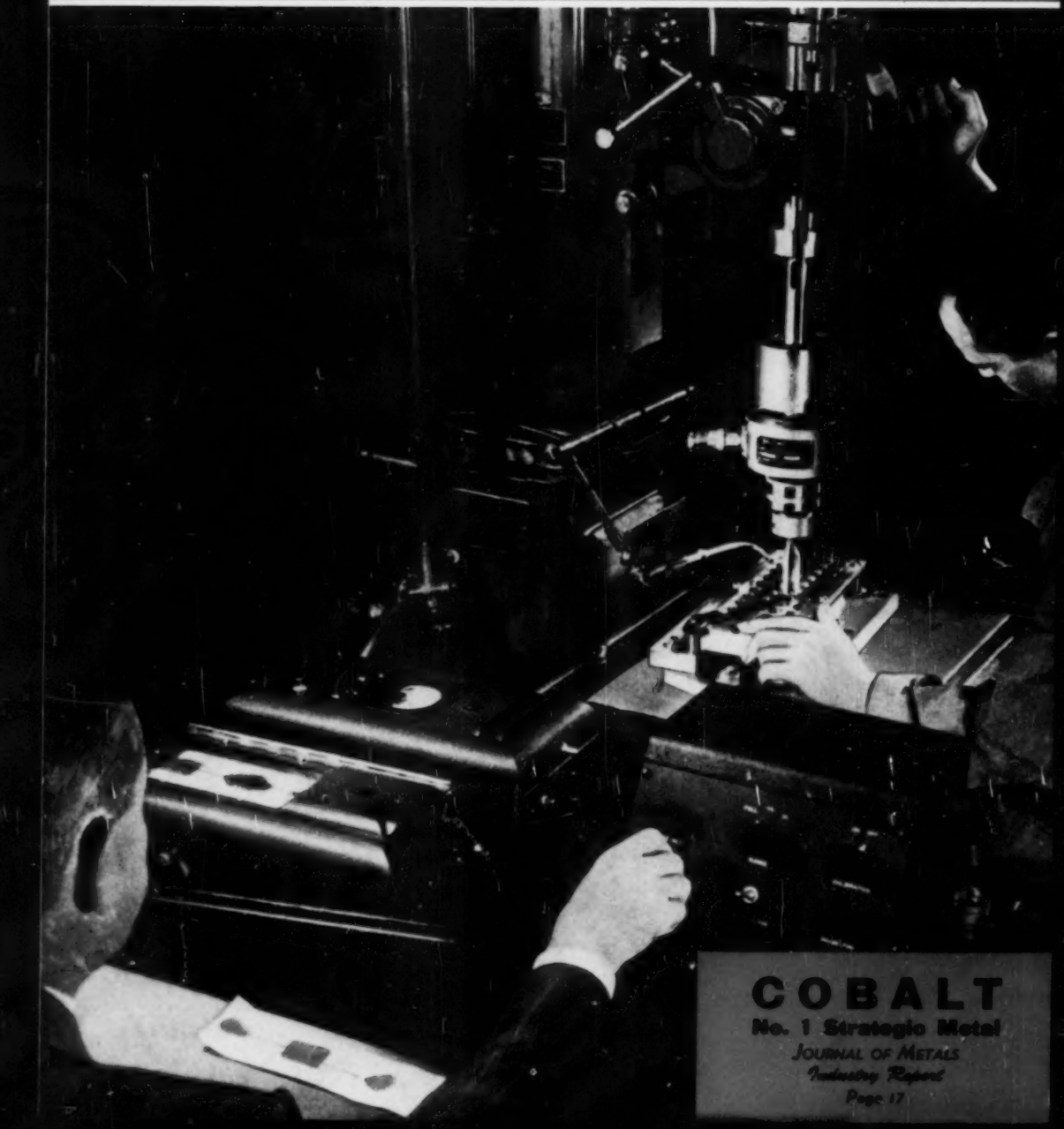
JANUARY, 1951
IN TWO SECTIONS — SECTION I

Journal of METALS



COBALT
No. 1 Strategic Metal
Journal of Metals
Industry Report
Page 17

COMBAT JOINT EROSION IN HOT METAL MIXERS

Taylor Sillimanite (TASIL) Brick, laid with TASIL No. 301 Cement in the zones of excessive wear (a 13½" thick band around the front, back, end walls and floor of the pour-out spout, and 18" x 18" x 6" blocks for jambs of pour-out spout) is tripling the life of hot metal mixer linings.

Field reports show over 13 months' service each for two mixers lined with TAYLOR SILLIMANITE

Field report on 1000-ton mixer

This company has just completed the third campaign in which more than a million tons each have been tapped on Taylor Sillimanite balanced mixer linings. The last campaign totaled 14 months with not a single brick replaced for the first 12 months. The material and labor costs for the campaign were 20% lower than the best campaign on high-heat duty firebrick linings.

Field report on 500-ton mixer

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Journal of METALS

VOL. 191, NO. 1 JANUARY, 1951

IN TWO SECTIONS—SECTION 1

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Metals Branch
American Institute of Mining and Metallurgical Engineers, Inc.
29 West 39th Street, New York 18

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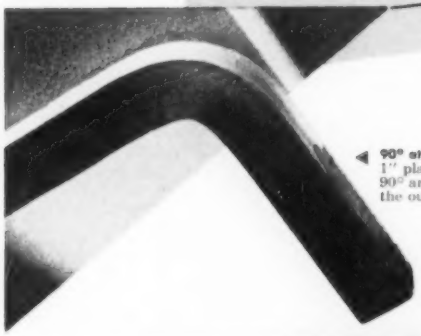
(Testing in accord with A.S.T.M. recommended practices.)



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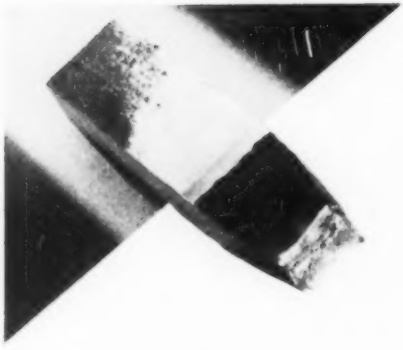

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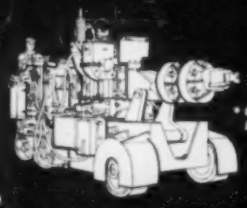

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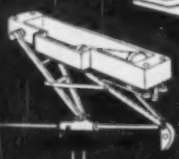

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Short Cuts . . .

United States Steel Corp. of Delaware, Carnegie-Illinois Steel Corp., H. C. Frick Coke Co., and United States Coal and Coke Co. on Jan. 1, 1951, was brought together into a single operating company called United States Steel Co. This unit will be a wholly-owned subsidiary of United States Steel Corp., and will replace four individual subsidiaries.

Fischer & Porter Co. will hold its next instrumentation course at the Hatboro, Pa., plant, Jan. 15 to 19, 1951. The course will cover manufacture, calibration, installation, operation and maintenance of primary and secondary process control instruments.

Electro Metallurgical Div. of Union Carbide and Carbon Corp. announced increases in ferroalloy prices averaging about 6.5 pct, effective immediately. Accepted spot orders and existing contractual commitments will be fulfilled at former prices. Quantity, sizing, and packing differentials in general remain unchanged.

Thomas Steel Co., Warren, Ohio, recently placed in operation a new high-speed tandem cold reduction mill, increasing annual capacity of cold rolled strip steel by 120,000 tons. The 10x26x24 in. 4-high, 3-stand tandem mill with a delivery of 2000 fpm, was engineered and manufactured by United Engineering and Foundry Co.; installation was made by F. H. McGraw Co.; and motors, controls etc. were furnished by Westinghouse Electric Corp. and General Electric Co.

Office of Technical Services of the U.S. Dept. of Commerce has just published one of the most complete bibliographies of captured technology from German industries. PB 101 458, *The German Chemical Industry, A Bibliography of the Chemical Metallurgical and Process Industries*, sells for $10 per copy.

United States Steel Co. (Carnegie-Illinois) has a new procedure establishing a price base at each producing mill of the company, and establishing revised extras and deductions for each of the different classifications of tin mill products. The new prices reflect an average increase of about 12 pct.

U.S. Atomic Energy Commission announced that its new production plants to be designed, built and operated by the E. I. du Pont de Nemours Co. will be located in Aiken and Barnwell counties, South Carolina, near the Savannah River. The new site will be known as the Savannah River Plant. The Commission emphasized that the operations will not involve the manufacture of atomic weapons.

Meet The Authors

T. L. JOSEPH

H. C. THEUERER

J. H. SCAFF

K. W. Nelson (p. 33) is chief hygienist for American Smelting & Refining Co., Salt Lake City, Utah. A Lt.-Cdr., USNR, he served in the Navy during the war, and was previously a chemist with the U.S. Food & Drug Administration. He received his B. Ed. degree from Superior State College, Wis., and did graduate work at Universities of Wisconsin, Maryland, and Harvard. His hobbies are fishing, photography, and music.

R. G. Treuting (p. 53), a member of the technical staff of Bell Telephone Laboratories, Murray Hill, N. J., studied at Yale University and received B.E. and Ph. D. degrees. A member of AIME, he has previously contributed to Transactions.

T. L. Joseph (p. 37) is professor of metallurgy and assistant dean, Minnesota Institute of Technology. He previously was head of the dept. of metallurgy, and had been supervising engineer of North Central Station of U.S. Bureau of Mines, Minneapolis. Since joining AIME in 1924, he received the J. E. Johnson, Jr. Award in 1927; the Hunt Award in 1937; was the Howe Lecturer in 1946; and Chairman of the Blast Furnace, Coke Oven and Raw Materials Committee in 1948. He has contributed about a dozen papers on blast furnace process or raw materials. His hobbies are gardening and fishing.

Harry Udin (p. 63), assistant professor of metallurgy at MIT, formerly was a Revere Copper and Brass Co. Fellow at MIT. Also, he previously had been associated with Reynolds Metals Co., and U.S. Metals Refining Co. He received his S.B. and Sc. D. degrees from MIT. He likes fishing and photography.

J. S. Bowles (p. 44) has returned to work in the Div. of Tribophysics, C.S.I.R.O., University of Melbourne, Melbourne, Australia. For the last three years, he studied with C. S. Barrett at the Institute for the Study of Metals, University of Chicago, where he was appointed a Fellow. He received his B.S. and M.S. degrees from the University of Melbourne, and in 1945 was promoted to the status of Lecturer at Melbourne.

L. C. Chang (p. 47) is a staff member of the Div. of Industrial Cooperation, MIT, having previously been associated with the Metals Research Lab, Carnegie Institute of Technology. Born in China, he studied at McGill University and Carnegie Institute of Technology, receiving his M.S. and D.S. degrees. An AIME member, he has written several papers on the physical chemistry of steelmaking. His hobbies are tennis, ping-pong, and bridge.

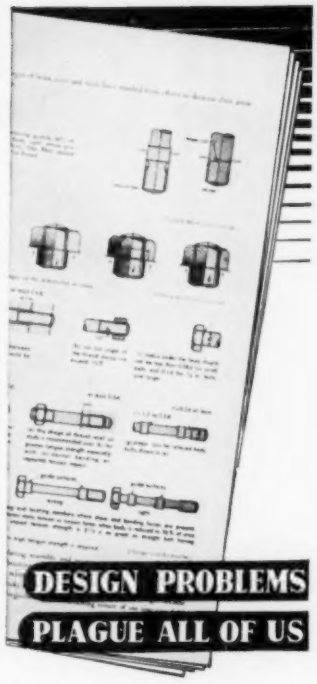
H. C. Theuerer (p. 59) is a member of the technical staff of Bell Telephone Laboratories, Inc. A graduate of Cooper Union and Columbia University, he received B.S. and M.A. degrees in chemistry.

W. C. Ellis (p. 53). See JOURNAL OF METALS, June, 1950.

J. H. Scaff (p. 59), a member of the technical staff of Bell Telephone Laboratories, Inc., Murray Hill, N. J., was born in Jackson, Tenn., and received his B.S.E. degree from University of Michigan. A member of AIME, his extra-curricular activities include fishing, hunting, and gardening.

M. E. Fine (p. 56). See JOURNAL OF METALS, July, 1950.

E. S. Greiner (p. 56). See JOURNAL OF METALS, June, 1950.



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Sales Engineer, 26 to 30, with metallurgical training and foundry experience, to do promotion and sales work on foundry accessories. Considerable traveling. Salary, $3600 a year, plus bonus. Location, New York City. Y4586.

Design Engineer, graduate, with at least 10 years' experience in heavy industrial plant maintenance and construction design, preferably metallurgical. Will have general charge of design and drafting for large combined copper smelter and electrolytic refinery maintenance and operation in metropolitan area. Salary, $8000 to $10,000 a year. Location, New York. Y4557.

Manufacturing Executive, 35 to 45, graduate, with experience in mechanical engineering and manufacturing methods, with emphasis on metal fabricating most desirable. Should have broad, practical knowledge of machines, dies and tools, and proved record in plant management. Salary open. Location, Illinois. Y4526C.

Metallurgist with malleable iron foundry experience, to take charge of metallurgical dept. of new foundry, to produce malleable iron fittings. Salary open. Location, northern Mexico. Y4323.

Foundry Superintendent, 40 to 50, metallurgical engineering graduate, with cast iron and alloy foundry experience, to supervise foundry, pattern shop, industrial relations, safety, etc. Salary, $7500 to $8500 a year. Location, New Jersey. Y4317.

Senior Industrial Engineer, 35 to 45, graduate of recognized engineering college. Must have had experience in metalworking industry as plant manager or assistant plant manager. Should have good knowledge of operating and general business control methods. Must be willing to travel; will spend about 50 pct of time away from home. Salary open. Headquarters, New York. Y4268.

Analytical Chemist, graduate, 30 to 35, with carbon steel, alloy steel and nonferrous experience, to make analyses of metal products. Salary, $4000 to $5000 a year. Location, New Jersey. Y4240.

Senior Metallurgist with degree and 5 to 7 years' experience in industrial metallurgy. Should have broad knowledge of metallurgy, including physics, mathematics, physical chemistry and metallography. Will be responsible for metallurgical experimental research development and establishment of quality control standards for all ferrous and nonferrous materials, processes, methods and equipment to insure adaptability for use in production. Salary, $4000 to $5500 a year. Location, Connecticut. Y4234(A).

Director of Purchasing, 35 to 45, graduate. Must be skillful in line of purchasing for electrical or metal fabrication plant, and have executive qualifications. Salary, $12,000 to $15,000 a year. Location, northern New Jersey. Y4230.

Metallurgists, graduates, for research and testing in laboratory of machinery manufacturer. Should have had from 5 to 10 years' experience in physical and metallurgical research and testing. Salary open. Location, northern New Jersey. Y4226.

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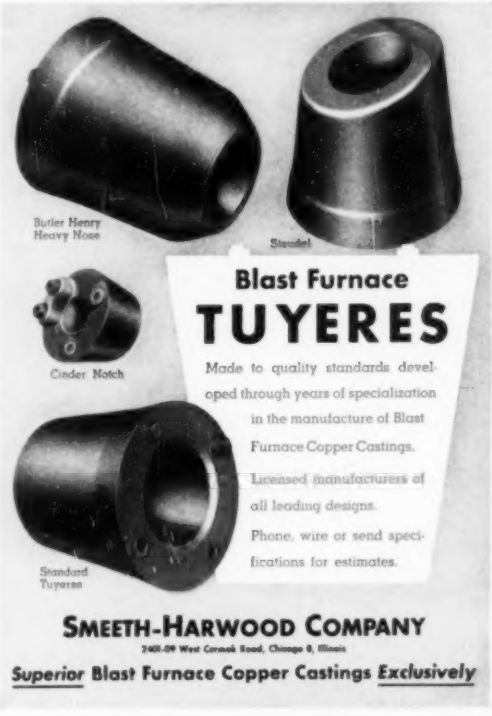

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JOURNAL OF METALS

— Coming Events —

Jan. 9. Society for Applied Spectroscopy, 6 pm dinner, Tosca's; 8 pm meeting, Socony-Vacuum Training Center, New York.

Jan. 15-17, 1951. AIME, Minnesota Section, annual meeting. Mining symposium conducted by Center for Continuation Study, University of Minnesota.

Jan. 15-18. Plant Maintenance Show, Auditorium, Cleveland.

Jan. 17. AIME, Western Section, Open Hearth Committee, Iron and Steel Div., Los Angeles.

Jan. 18-20. Society of Plastics Engineers, annual national technical conference, Hotel Statler, New York.

Feb. 6. Society for Applied Spectroscopy, 6 pm dinner, Tosca's; 8 pm meeting, Socony-Vacuum Training Center, New York.

Feb. 18-22. AIME, annual meeting, Jefferson Hotel; Metals Branch session, Statler Hotel, St. Louis.

Feb. 21. AIME, Western Section, Open Hearth Committee, Iron and Steel Div., Los Angeles.

Mar. 5-9. ASTM, spring meeting and committee week, Cincinnati.

Mar. 11-14. American Institute of Chemical Engineers, regional meeting, Greenbrier, White Sulphur Springs, Va.

Mar. 13-16. National Assn. of Corrosion Engineers, 1951 conference and exhibition, Hotel Statler, New York.

Mar. 19-23. Western Metal Congress and Exposition, Civic Auditorium and Exposition Hall, Oakland, Calif.

Mar. 21. AIME, Western Section, Open Hearth Committee, Iron and Steel Div., Los Angeles.

Apr. 2-4. AIME, Open Hearth and Blast Furnace, Coke Oven and Raw Materials Conference, Iron and Steel Div., Statler Hotel, Cleveland.

Apr. 2-5. ASME, spring meeting, Atlanta-Biltmore, Atlanta.

Apr. 13-14. AIME, Institute of Metals Div., New England regional conference, Taft Hotel, New Haven, Conn.

Apr. 16-18. American Society of Lubrication Engineers, Bellevue-Startford Hotel, Philadelphia.

Apr. 23-26. American Foundrymen's Society, annual convention, Buffalo, N. Y.

Apr. 25-26. Metal Powder Association, annual meeting, Hotel Cleveland, Cleveland.

May 7-11. Greater New York Industrial Show, 71st Regiment Armory, New York.

May 9-11. Engineering Institute of Canada, annual meeting, Mount Royal Hotel, Montreal.

May 13-16. American Institute of Chemical Engineers, regional meeting, Hotel Muehlebach, Kansas City, Mo.

May 23-24. American Society for Quality Control, annual convention, Hotel Cleveland, Cleveland.

June 11-15. ASME, semi-annual meeting, Royal York, Toronto, Canada.

June 18-22. ASTM, annual meeting, Atlantic City, N. J.

Sept. 25-28. ASME, fall meeting, Minneapolis.

Oct. 15-17. AIME, Institute of Metals Div., fall meeting, Detroit-Leland Hotel, Detroit.

Oct. 22-24. Metal and Nonmetallic Mining Convention, Biltmore Hotel, Los Angeles.

Oct. 29-Nov. 3. AIME, fall meeting, Mexico City.

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ELECTROMET Data Sheet

A Digest of the Production, Properties, and Uses of Steels and Other Metals

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VANADIUM...the metal that accentuates the effects of other alloying elements

Vanadium is usually added to steel or iron along with other alloying metals, such as manganese, tungsten, nickel, or chromium. It enhances the effect of these other alloys and helps to improve the physical properties of the metal. Generally it is used in quantities of less than 0.50 per cent, but even in these small amounts it is responsible for many marked improvements in the quality of iron and steel.

One of the most notable functions of vanadium is its effect in improving the dynamic properties of steel, such as fatigue and impact resistance. It also gives an inherently fine grain size to both steel and iron.

In high-speed tools, vanadium contributes wear resistance and red hardness. It is also an important alloy in many types of permanent magnet steels. These and many other types of special-purpose steels contain more than 0.50 per cent vanadium to enhance certain properties.

Dynamic Strength for Steels

The principal effect of vanadium in engineering steels is that of refining grain size. It is usually added in amounts of 0.10 to 0.25 per cent.

Fig. 1. Steels in which vanadium is an alloy have outstanding dynamic strength. That is why they are frequently used in such heavy-duty service as springs and axles in diesel locomotive trucks.

In the lower carbon ranges, vanadium steels are especially suited for carburizing and are used for such applications as hand tools, bearings, and pistons. Vanadium-bearing steels can also be nitrided effectively.

Vanadium contributes fatigue and impact resistance and also strength and ductility to spring steels. The famous chromium-vanadium (SAE 6100 series) and manganese-vanadium spring steels are outstanding examples of this use. Besides being used as springs, these steels are frequently used for axles, shafts, and other highly stressed moving engine parts.

Red Hardness in Tools

Practically all fine tool steels contain vanadium. In high-speed steels, vanadium content usually ranges from about 0.50 to 2.50 per cent, although higher percentages are sometimes used. Other alloy tool steels usually contain from 0.20 to 1.00 per cent vanadium.

Vanadium is a strong carbide-former and forms very hard and stable carbides. These vanadium-carbides are probably the main reason for the excellent wear resistance and edge-holding properties of vanadium tool steels. The persistence of the vanadium-carbides is largely responsible for the cutting qualities at red hardness of high-speed tool steels.

Adds Strength to Cast Iron

In amounts of 0.10 to 0.15 per cent, vanadium increases the strength of cast iron from 10 to 25 per cent, and adds a considerable amount of toughness. Cast iron containing vanadium is especially valuable in such applications as steam locomotive cylinders, valve and piston bushings, piston rings, and similar parts. In steam engines and diesel motors, vanadium cast iron cylinders greatly outlast those of ordinary cast iron. Chromium-vanadium cast iron rolls, containing up to 2 per cent chromium, have been used successfully in steel mills for a great many years.

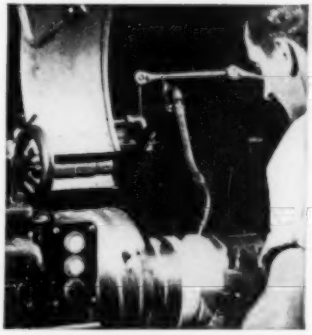

Fig. 2. Nearly all fine tool steels contain vanadium. It promotes fine grain size, high wear resistance, and greater control of hardenability. Vanadium also contributes to the red hardness of high-speed tool steels.

Cast iron in which vanadium is the sole alloying element is used primarily in applications where temperatures are moderately high and in heavy sections requiring uniform hardness without brittleness.

ELECTROMET Vanadium Alloys

ELECTROMET produces three grades of ferrovanadium in various sizes for the production of vanadium-bearing steels and irons. Each grade has a definite range of carbon and silicon contents and is especially adapted to assure the best results in the different requirements of iron and steelmaking.

Write for a copy of the booklet, "ELECTROMET Ferro-Alloys and Metals." It contains many useful facts about the use of ferrovanadium. The booklet also describes over 50 other alloys and alloying metals produced by ELECTROMET.

The term "Electromet" is a registered trademark of Union Carbide and Carbon Corporation.

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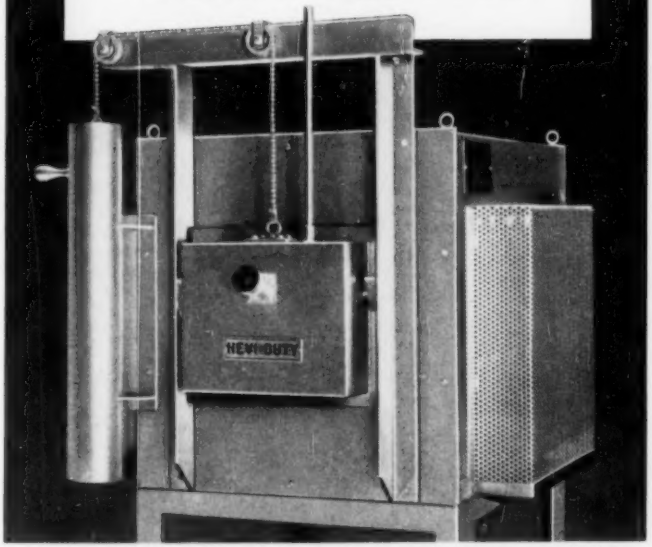

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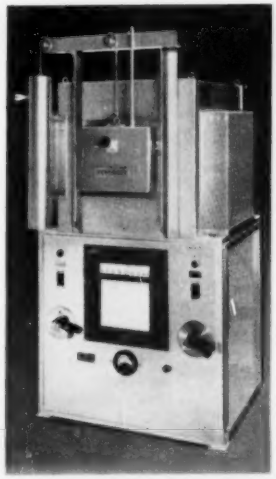

Silicon Carbide (* Globar) heating elements located above and below a sealed muffle assure even heat distribution throughout the work chamber. Connections for using a protective atmosphere are provided.

The furnace is available in several sizes with or without the control base as shown in the insert. Transformers, pyrometer and circuit breakers can be supplied as required.

Write for bulletin HD-741

* trademark, Carborundum Co.

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1—GOGGLE VALVE: *Edgar E. Brosius Co., Inc.* announces the new Brosius Westling goggle plate valve that permits fast mechanical operation with protection against leakage. Higher structural strength has been combined with other new features, and the valves simple operation permits opening or closing by one man in from ½ to 3 min. It can be operated manually or be motor driven and interlocked when the service warrants the extra cost.

2—GEIGER COUNTER: *Victoreen Instrument Co.* has introduced a new portable geiger counter, Thyac 389, that provides regulated high voltage and plate voltage. Power supply regulation eliminates instrument drift, reduces calibration time, and substantially reduces battery costs. The standard 1B85 beta gamma counter tube may be replaced by the LB106 mica window counter tube, the 1B124 gamma ray tube, the 1B125 cosmic ray tube, or any other tube having the RMA type 1A-82 coaxial plug-in base. Convenient fingertip control affords ease of operation.

3—MONOGAS GENERATOR: *Westinghouse Electric Corp.* has added a Monogas generator to the line of protective atmosphere equipment. Monogas is a non-decarburizing, neutral atmosphere that consists essentially of nitrogen, has low hydrogen and carbon content, and with carbon dioxide, oxygen, and water vapor removed. The generator and scrubber are one unit, utilizing the waste heat of combustion in the Exogas generator in reboiling the CO_2 scrubbing chemical.

4—INDUCTION MOTORS: A new line of heavy-duty, wound-rotor induction motors has been announced by *Electric Machinery Mfg. Co.* The motors give variable speed drive and are advantageous on applications requiring high starting torque and low starting current, or long acceleration periods. Built in ratings from 30 to 1500 hp, drip-proof construction is furnished as standard on these motors.

5—ELECTROPLATING AGENT: An addition agent for electroplating baths called Wes-X has been developed by *Westinghouse Electric Corp.* When added to cyanide copper-plating baths, the plated copper is smoother, less grainy, and can be laid down at a faster rate.

6—V/A CELL: The V/A Cell is a new precision flow transmitter developed for differential pressure applications. It is a through-flow instrument of the variable area type and measures a bypassed portion of the main line flow. Continuous self purging is thus provided. It is mercuryless but does not utilize a diaphragm. The cell is applicable to services on liquids, gas, and vapor streams including steam. *Fischer & Porter Co.*

7—CARBON CONTROL: To measure and control the carbon potential of furnace atmosphere directly in terms of per cent carbon, *Leeds & Northrup Co.* has developed a new automatic Microcarb control. Principal feature is a Carbohm detecting element that projects into the furnace work chamber like a thermocouple, and electrically senses the carburizing potential of the furnace atmosphere. It can be ordered as an integral part of new Homocarb equipments, or can be added to certain furnaces now in service.

8—INDUSTRIAL CONVEYOR: *Industrial Engineering & Mfg. Co.* has added a new conveyor model to its present standard line, the 100-U. It is 5 ft long, and is equipped with an 8-in. neoprene-impregnated belt with flights 1⅛ in. high spaced on 18-in. centers. Belt speed is approximately 125 fpm. Takeup mechanism provides for ample belt adjustment. Pulleys come with permanently lubricated and sealed ball bearings.

9—SHEET METAL: For clearer reception and transmission Electroshield metal is recommended by the *American Cladmetals Co.* It has a magnetic base and is clad on each side with a nonferrous conductor; made in light and heavy sheets up to about 35 sq ft in area.

10—HEATING MAT: To alleviate discomfort in chilly working areas the new Snook Dura-Thermal Mat is recommended. Coils of hard steel wire are wound over a 280-watt, 120-v metal-encased element, distributed over the 16x27-in. mat area in a pattern assuring even, overall heating. The whole is enclosed in a heavy frame with protective rails of tubular burnished aluminum. 15 pct of output is radiant heat and the balance convective. Price: $21.50. *Walter B. Snook Enterprises.*

11—HELIARC TORCH: A new, lightweight, air cooled Heliarc torch for inert gas-shielded arc welding comes from *Linde Air Products Co.*, Union Carbide and Carbon Corp. The torch has a two-position welding head and needs no water cooling. It has a maximum current capacity for continuous duty of 75 amp and is designed for welding thin-gage materials. By interchanging the collet nut and torch cap, the angle of the torch head can be changed to a 60° backward angle permitting welding in tight spots. Steel collets are available for 0.020 in., 0.040 in. and 1/16 in. diam electrodes.

12—PROTECTIVE COATING: In handling acids, alkalies and solvents a new painting method will in most cases eliminate baked coatings or conventional lining methods for wood and steel tanks. Three brush-on coats of Carbo Kote 6020 provide a lining 0.036 in. thick, that is proof against a 30,000 v spark test and resists most solvents, acids and alkalies, up to 350°F. *Carboline Co.*

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13—FLASH WELDER CONTROL: Having transformer capacity up to 500 kva, a control known as Hydra-Flash has been developed for use with any make of flash welder. It is an hydraulic unit with adjustments calibrated, making duplication of setups as easy as turning a dial. It will operate several million cycles without maintenance other than regular lubrication and has been designed for conversion of mechanically driven flash welders to hydraulic operation. *Kingsley A. Doutt.*

14—HOT WORKING DIE STEEL: Prestem, a new hot working die steel, marketed by *Heppenstall Co.* in the form of solid press dies, insert dies, upsetter dies and punches, will be useful as a solid die or insert die for drop forge plants making press and upsetter forgings for the automotive, aviation, and farm implement industries. It has a ready machinability at comparatively high hardness, a high impact resistance, and an ability to be water cooled during press forging operations.

15—ALUMINUM BRIGHT DIP: Development of Kaiser Aluminum Bright Dip, a new and inexpensive process for brightening aluminum and its alloys, is announced by *Kaiser Aluminum & Chemical Corp.* Dipped articles may be color-lacquered for outdoors. The process brightens mill-finish sheet and articles for anodizing and dyeing; increases total reflectivity of buffed articles; and brightens articles without buffing.

16—PRE-SHAPED STEELS: Steel bar stock cold drawn in special sections to fit specific uses is available from *A. Milne & Co.* Such sections will minimize or virtually eliminate machining operations in the quantity-production of steel component parts. The types of steel now available in Pre-Shaped form include various standard SAE and AISI carbon steels, case hardening steel, standard mild steels and free cutting steels.

Free Literature

20—PLASTIC FIRE BRICK: A 44-p. edition of *The Inside Story of Plastic Fire Brick* will be of interest to every steel man. A most comprehensive and well illustrated booklet, it is published by the *Laclede-Christy Co.*

21—DEPTH HARDENING: Bulletin 13, distributed by the *Wilson Carbon Co., Inc.*, describes a simple procedure for gradient depth hardening of large or small machine parts, cutting and impact tools, wire, hand tools, and engraved stamping dies. It shows how any kind of steel can be gradient depth hardened with a positive change in grain structure from the steel surface through the ductile area and clear through the core by the use of Wilcarbo heavy duty pack-hardening compound or Hi-Speed-It steel hardening compound.

22—ANTI-CORROSION COATING: Corrosion resistance superior to conventional zinc coatings with cost savings is claimed for Zincilate, a one-coat, self-protecting, anti-corrosion coating described in an 8-p. illustrated bulletin from the *Industrial Metal Protectives, Inc.* Case histories and typical applications are given.

23—FLYASH HANDLING: Compiled in question and answer form, a booklet on hydraulic and pneumatic ash and flyash handling systems is offered by the *Beaumont Birch Co.* Schematic drawings of arrangements under specific conditions, as well as diagrams of basic arrangements, are included.

24—ELECTRIC FURNACES: A new book describing 50 to 50,000 kva electric furnaces for all smelting and refining operations such as matte and speiss smelting, oxide reduction, calcium carbide, non-metallic melting, ferro-alloys, special applications, non-ferrous refining, and iron and steel furnaces, is offered by *Pittsburgh Lectromelt Furnace Corporation.*

25—MULTI-POLE SWITCHES: Catalog 1950-JR of the *Electro Switch Corp.* tells of rotary multi-pole tap and transfer switches that conform to Navy and Underwriters' Laboratories requirements. Sectional, cut away, and exploded views of typical Type JR switches show details of the switch design. Four, eight, and sixteen-position switches are listed.

26—ATMOSPHERE FURNACE: Available to the production heat treater is the rotary retort controlled atmosphere furnace, described in bulletin SC-147 from the *Surface Combustion Corp.* The furnaces are used for gas case carburizing, homogeneous carburizing, dry cyaniding and clean hardening.

27—INCO NICKEL ALLOYS: *Standard Alloys for Special Problems*, a 16-p. catalog tells of uses and typical applications of Inco nickel alloys, their compositions, mechanical properties, and physical constants. Ranges of sizes produced in all of the standard mill forms are listed. *International Nickel Co.*

28—CLOSE TOLERANCE TUBING: *Tube Reducing Corp.* offers an 8-p. folder, R-3, on compression-formed tubing, discussing compression-forming process, tolerances, surface finish, decarburization, mechanical properties, types, shapes and sizes. Profilometer readings are given. Photos show how dies compress tubing over a mandrel and typical close-tolerance parts that can be produced, including tapered and special internal bore shapes.

29—SILLIMANITE CEMENTS: For bonding linings in any high temperature furnace Taylor Sillimanite, mullite-base cements are used in the steel, other metallurgical, glass, and chemical process industries. An 8-p. illustrated bulletin discusses the properties and applications. *Chas. Taylor Sons Co.*

30—SCIENTIFIC EQUIPMENT: An attractive edition of the *Eberbach Announcer*, No. 50 10 40, offered by *Eberbach & Son Co.*, describes in detail scientific equipment for metallurgical laboratories.

31—HARDENING OF STEEL: Methods to be used in the preparation of stainless steel for hardening are discussed in a new bulletin. Stainless steel parts machined to a tolerance of 0.25 to 0.0001 in. after hardening by the Super Scottsonizing method, require no grinding or lapping. *C. U. Scott & Son, Inc.*

32—INSTRUMENT CATALOG: *Wheelco Instruments Co.* offers a new condensed catalog describing their typical Wheelco indicators, controllers and combustion safeguards. Current prices are given.

33—WELDING MANUAL: *Eutectic Welding Alloys Corp.* offers a manual of welding engineering and design—Series No. 1, containing engineering data compiled by the company, as well as information on the art of welding in all its phases.

34—SPRAY VALVE: With the Farval spray valve of *The Farval Corp.*, either grease or oil can be sprayed onto open gearing, slide surfaces, or any other area where it is desirable to apply a measured amount of lubricant at regular intervals. It can be operated wherever compressed air is available, either as an addition to a regular Farval Dualine lubrication system or in a complete system of spray valves, served by either a manual or an automatic pumping unit.

35—CORROSION-RESISTANT ALLOYS: Brief descriptions of the Ampco alloys for corrosion applications, along with their physical properties and a guide to chemical agents, are given in a 4-p. folder on Ampco Metal. *Ampco Metal, Inc.*

Counsel Offered

ON METAL PROBLEMS

Because of unusually heavy industrial and defense demand, rationing of nickel has been in force since July 1st. However, we believe that dissemination of technical data and service experience can help to promote the intelligent utilization of critical materials, so essential in these times. We shall, therefore, continue to issue information on new developments and user experience with nickel-containing materials.

"INCO" TECHNICAL SECTIONS

Consultation on technical problems relating to alloys containing nickel is invited. Consult the nearest Technical Field Section of INCO Development and Research Division listed below:

CANADIAN SECTION
25 King Street, West,
Toronto 1, Ont.
Tel. Elgin 7471

CENTRAL ATLANTIC COAST SECTION
67 Wall Street,
New York 5, N. Y.
Tel. Whitehall 4-1000

CHICAGO SECTION
333 N. Michigan Avenue,
Chicago 1, Ill.
Tel. Franklin 2-4030

CINCINNATI SECTION
Carew Tower
Cincinnati 2, Ohio
Tel. Parkway 1631

DETROIT SECTION
General Motors Building
Detroit 2, Mich.
Tel. Trinity 5-3436

EMPIRE STATE SECTION
Genesee Valley Trust Bldg.,
Rochester 14, N. Y.
Tel. Locust 5884

NEW ENGLAND SECTION
75 Pearl Street
Hartford 3, Conn.
Tel. Hartford 7-0383

PITTSBURGH SECTION
Grant Building
Pittsburgh 19, Pa.
Tel. Atlantic 1-9546

ST. LOUIS SECTION
Ambassador Bldg.,
St. Louis 1, Mo.
Tel. Garfield 4197

TEXAS SECTION
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Houston 2, Texas
Tel. Charter 4234

TWIN CITIES SECTION
Northwestern Bank Bldg.,
Minneapolis 2, Minn.
Tel. Geneva 0631

WEST COAST SECTION
Petroleum Bldg.,
Los Angeles 15, Calif.
Tel. Prospect 2496

STOCK AND SERVICE CENTERS FOR "INCO" PRODUCTS

The following are sources of supply for primary nickel for alloying purposes. Through casting specialists, they are prepared to offer technical service on the production of ferrous and non-ferrous castings containing nickel.

ATLANTA 3
J. M. Tull Metal & Supply Co.
265 Marietta Street
Tel. Walnut 3528

BALTIMORE 17
Whitehead Metal Products Company, Inc.
413 West North Avenue
Tel. Lafayette 2300

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Tel. Cleveland 1475

CAMBRIDGE 39, MASS.
Whitehead Metal Products Company, Inc.
281 Albany Street
Tel. Trowbridge 6-4600

CHICAGO 23
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3344 South Pulaski Road
Tel. Bishop 7-7700

CINCINNATI 29
Williams and Company, Inc.
3231 Fredonia Avenue
Tel. Capitol 3000

CLEVELAND 14
Williams and Company, Inc.
3700 Perkins Avenue
Tel. Utah 1-5000

COLUMBUS 8, OHIO
Williams and Company, Inc.
851 Williams Avenue
Tel. Klondike 1623

DALLAS 9
Metal Goods Corporation
6211 Cedar Springs Road
Tel. Elmhurst 3271

DENVER 5
Metal Goods Corporation
Municipal Service Center
37th at York
Tel. Acoma 5891

DETROIT 10
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Tel. 25834

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Tel. Central 8881

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Tel. Talbot 1506

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Steel Sales Corporation
2301 Grand Avenue
Tel. Victor 7270

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1400 South Alameda Street
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Tel. Daly 8-6840

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Tel. Tuxedo 5201

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Tel. Franklin 9-5826

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3100 Nineteenth Street
Tel. Mission 7-1104

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Tel. Elliot 4764

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East 320 Trent Avenue
Tel. Madison 2419

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Tel. Syracuse 3-0186

TOLEDO 2
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Tel. Adams 8101

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THE INTERNATIONAL NICKEL COMPANY, INC.

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Advanced principles of machining high temperature alloys have been developed by the Air Materiel Command. A 2½-year, $100,000 research program, conducted with the assistance of Ford, Curtiss-Wright, MIT, and Metcut Research Assn, engineers, has resulted in the development of new ways of cutting super-hard alloys used in jet-engines, rockets, and guided missiles.

British industry faces a sulphur shortage that may prove serious. World output is estimated at about 5,000,000 tons, but existing deposits are being exhausted rapidly and few new ones are being found. U.S. is the largest producer accounting for 90 pct of the world output and almost all of the world exports. U.S. is considering curtailment of exports in 1951 and British acid plants are being closed down. Conversion of sulphur burning plants to the use of pyrites is the British long-term policy, but production from pyrites is more costly.

The British Iron and Steel Research Assn. proposes the erection of a pilot plant in South Wales for the recovery of sulphuric acid from steel plant liquid waste. The plant will produce 1 ton of sulphuric acid a day using the waste liquid acid heretofore discharged as a basic raw material. If the plant is a success, a production plant will be built with a possible output of 20 to 40 tons a day in the case of a large steel mill.

Army engineers are testing a line of earth-moving and other construction equipment such as tractors, cranes, scrapers, rooters and dozers, all designed to a weight limit of 8 tons. Some machines are standard, others are specially constructed with weight and bulk kept to specified limits. This equipment is for use where airborne transportation is necessary.

Fisher Body Pittsburgh plant is using television to expedite loading scrap into railroad cars. The operator of the scrap baler can view the car and determine when the car must be moved to assure uniform fill.

The Geneva Tin Conference left much to be desired. An agreement to stabilize the tin market by regulating exports and production and by a buffer stock resulted in no agreement. Producers sought export quotas and restrictions of output with a buffer stock intended to be no more than a useful mechanism to achieve a final adjustment between supply and demand. U. S., championing consumer countries, wanted the buffer stock to be a governor relating to supply and demand and wanted export quotas to provide the necessary reserve to prevent the buffer stock from becoming unwieldy. The Americans wanted a 30,000 ton buffer stock before production was curtailed, and Malaya and other producing countries thought of a buffer stock of about 10,000 tons and finally 25,000 tons; but they would go no higher. Disagreement on proposed price ranges was even sharper.

A stroboscopic device that stops motions recurring as often as 300,000 per sec has been developed by the Navy for either visual or photographic observation. The heart of the device is an electron tube with variable pulse rate that illuminates the subject in a manner similar to the Snooperscope developed for night-time riflemen.

The Persian Government has purchased 100,000 tons of rails, sleepers, fastenings, and other rail-laying materials. The rails will be used for the completion of the Teheran and Meshed Railway to link Tabriz with Teheran.

Drift of Things . . . . . as followed by Edward H. Robie

DEMAND and supply of engineers, present and future, has had more than the usual amount of attention in the past year. Since the end of the last World War, new peaks have been attained in engineering enrollments in the colleges. The profession seemed to be particularly attractive to the GI's who took advantage of the Government's offer to finance their educations. In the prewar decade, some 11,000 engineers had been graduated annually. The figure rose to 19,000 in the academic year 1946-47, to 31,000 in 1947-48, to 47,000 in 1948-49, and to 51,000 in 1949-50. This for a time saturated the market, and those graduating last June found a buyer's market.

A year or more ago the Dept. of Labor came out with a flat statement that *"the number of graduates will greatly exceed the number of engineering job openings in the next few years."* This was based on a study that indicated that the number of graduates needed would approximate 17,000 or 18,000 annually for the next several years. Contrasted with this, it was estimated that 36,000 would be graduated in 1951 and 29,000 in 1952. Unfortunately this pessimistic statement received wide publicity and discouraged many young men from entering engineering. Difficulties reported in obtaining jobs six months ago added to their feeling that perhaps for the next few years engineering was a poor field to enter. Freshmen engineering enrollment currently is only about 27,000. Instead of more than 5 pct of high school graduates going into engineering, as in 1947, this year only 2.2 pct selected this field.

Selective Service has indicated that the upper half of the current 27,000 students will be deferred to continue their education next year, or 13,500. Those in the upper two thirds of the sophomore class, or 9000, could continue as juniors; and the upper three quarters of the juniors, or perhaps some 7000, could graduate in 1954. Against this, Dean Hollister, of Cornell, believes 20,000 engineering graduates will be needed annually for peacetime needs alone, and that the present emergency will increase this number, for both civilian and military needs, to 30,000.

If Selective Service were not withdrawing any engineering students at all, Dean Hollister estimates the number of graduates in 1951 at 32,500; in 1952 at 21,900; in 1953 at 17,000; and in 1954 at 12,400.

It is plain that the top half of high school students, particularly those who rank high in mathematics, science, and may we add English, should be apprised of the excellent opportunities that seem almost certain to be open to engineering graduates in the next few years. AIME members can help to do this, and present engineering students can tell their younger brothers and their friends that this is a field of high promise.

Furthermore, those who feel no particular urge to go out and shoot somebody, and have the intellect to stay in the top half of their class at an engineering college, have some assurance that they will be allowed to serve their country in a more constructive way than by carrying a gun. Engineers Joint Council, of which the AIME is a component society, is doing everything possible, through its Engineering Manpower Commission, to see that an adequate flow of engineers shall come out of our schools in the future years, and that their talents are thereafter used to the best advantage.

Misery Loves Company

Our good friend Austin Wright, general secretary of The Engineering Institute of Canada, writes: "You will have no idea of the kick that I got out of your item in the 'Drift of Things' in the November issue. Your experience with your directory was so much like ours that it really did me a lot of good to read your account. Change the name of the organization and your article might have been written by some one in the Engineering Institute. However, I hope that by the time you get through with it all you will not be out as much money as we were on the deal. It cost us $18,000 to print 15,000 copies."

Well, our printer's bill, for which we have just reluctantly signed a check, was for $15,999.11, for 16,000 copies. (We had twice as many pages as the Canadian volume but they were only half as large.) In addition we charged some $3000 against the volume for salaries, postage, mailing expense, post cards circulated to members, and aspirin for all concerned.

Book Manuscripts Wanted

Twenty years ago the family of the late Seeley W. Mudd contributed $100,000 to the AIME, establishing a fund whose income was to be used *"for the advancement of the sciences of mining and metallurgy by the encouragement of research and the dissemination of knowledge, and for the promotion of the welfare of engineers engaged in the professions of mining and metallurgy."* A further suggestion was that preference be given to projects of particular benefit to young engineers. Accumulated unspent income in the fund now totals some $36,000. A part of the income heretofore has been used to publish or purchase books, subsequently given free to new Junior Members of the Institute. Money in the fund also has been used to underwrite preparation and publication of such books as: *"Industrial Minerals and Rocks," "Elements of the Petroleum Industry," "Coal Preparation," "Basic Open Hearth Steelmaking,"* and *"Biringuccio's 'Pirotechnia'."*

The Committee administering the fund is now seeking material for new volumes, either for free distribution to Junior Members or, in the latter category, for general sale. If any member of AIME has the material for a good book in his system, or knows of some one who has; or if he can suggest a topic and an author for a book that will fill a gap in the literature; then we should like to be advised.

New Edition of Agricola Popular

As this is written, early in December, we received orders for more than 500 copies of the reprint of the Hoover translation of Agricola's *"De Re Metallica."* This represents but four days' mail, following our circular to members. The total edition of the reprint was 1000 copies, of which half had been reserved for us. The response exceeded our expectations greatly. We shall do what we can to get more copies, but the demand may well amount to 1000 copies from AIME members alone.

For Thirsty Members Abroad

Stanley Lefond sends us the accompanying picture from Sfax, Tunisia. He says that he knew the AIME was not in too good shape financially, but he did not know that we had to resort to such measures as this.

U. S. and U. K. Releases Data on Atomic Energy

The Governments of the United States, the United Kingdom and Canada have adopted a revised Declassification Guide, which will permit the publication of certain information necessary to the design, construction and operation of specified low-power nuclear reactors used for research purposes.

Technical information declassifiable under the new Guide must be reviewed prior to publication, in accordance with the declassification procedures in effect in each of the three nations. Details on design, construction and operation of the newly declassified reactors will be contained in a number of technical papers to be published after clearance through the declassification system. Values of pertinent nuclear constants of uranium, required for work in this field, will be published in a special technical report to be issued by the atomic energy agencies of the three governments.

The three governments have determined that the release of information under the revised Guide will speed the training of nuclear reactor engineers and technicians and will hasten atomic energy development in these countries, particularly for peacetime applications. It was determined that this information would not aid rival nations in the development of military applications of atomic energy. Low-power reactors are not used for producing atomic weapons or power.

The information now releasable describes what must be known in order to assemble and operate a low-power research reactor. Before such a reactor can be built by a private institution, however, the permission of the government to use the necessary fissionable materials is required.

Belgium University Seeks Aid in Library Rehabilitation

While the famous chimes given to the library of the University of Louvain, Belgium, by a group of American engineering societies after World War I, survived the fire and bombing of World War II, the books in the library were destroyed. The building has been restored, shelves have been replaced, and some books have been collected. But few recent books in English fill those empty shelves.

A plea has been made to American engineers to help in this matter. The CARE UNESCO Book Fund will channel any donations for books to Louvain; and a bookplate inscribed with the name of the company or organization will be inserted on all gifts of $10 or more. While Belgium and Europe were in a long war, resulting in an intellectual blackout, American research and progress continued. Recovery in this area can be speeded by making American knowledge available through subscription to Louvain through the CARE UNESCO Book Fund.

New Galvanizing Process

A new method of cold galvanizing for surface protection of steel and iron has just been announced by the Chase Chemical Corp., N.Y. It is claimed that extensive testing over a two year period has proved that the process, which utilizes Zinkrich Cold Galvanizing Compound, equals and in many cases exceeds the performance of other surface protection techniques including electroplating, hot-dipping, cementation, spraying, and painting.

Zinkrich, when applied to steel or iron surfaces, actually combines with the surface to produce electrical continuity, leaving a coating of chemically pure zinc. In cases where it is applied directly onto adhering rust, it induces the rusted area to create its own protective, non-flaking coating, arresting further rust. Zinkrich is applied with an ordinary paint brush, electric spray gun or cold dip, and no special equipment or personnel training is necessary.

Scratch tests made on Zinkrich have not evidenced any rust after the metal was submerged in salt water for two years. Specimens of steel, both bright and rusty were treated with Zinkrich, and immersed in sea water for two years. Final removal from the water revealed that both samples were unaffected and were free of any loose rust after their long immersion period.

EJC Nominees Appointed On National Science Foundation Board

Donald H. McLaughlin, AIME President; Edward L. Moreland, principal in the consulting firm of Jackson & Moreland; and Audrey A. Potter, dean of engineering, Purdue University, were recently named by President Truman as members of the new 24-man Board of National Science Foundation. These three engineers were among the nominees presented to President Truman by Engineers Joint Council. With the EJC list of nominees went a strong recommendation that applied science, as represented by engineers, be given appropriate consideration on the Board of National Science Foundation.

Library Photoprint Service Revised

To conserve time and the inconvenience of trying to locate material for photoprinting, the Engineering Societies Library has revised this service. For material at the library, copies can be supplied as negative prints, white on black, for 40c, minimum charge $1 per order. Any two facing pages which together measure not over 11x14 in. can be taken on one print. Larger material will require one print per page. If material is not in the library, search will be made on request and if available elsewhere there will be the regular charge of 40c a print and an additional charge of $3 service fee for locating the article. There will be no charge if the material cannot be located.

Members of the AIME, ASCE, ASME, and AIEE who order work for their personal use will receive a discount of 20 pct on the fee for locating the article and a reduction of 5c on each photoprint.

Continental Steel Buys Furnace

A single-zone pusher-type billet heating furnace is being designed and built for Continental Steel Corp.'s new rod mill at Kokomo, Ind., by Salem Engineering Co., Salem, Ohio.

The furnace will heat steel bars 2½ x 2½ in. x 30 ft long at a nominal rate of 60 tons per hr. The furnace is equipped to burn heavy fuel oil; and will be complete with Salem's needle-type metallic recuperator. Construction is scheduled to start early in 1951.

All-Welded Aluminum PT Boat

An all-welded aluminum patrol torpedo boat, the first of its kind, has been launched by the Navy. The ship, USS PT-811, was designed to replace the famed "splinter fleet" of PT boats of World War II. Similar aluminum ships had been built that were 95 ft long, with a beam of 25 ft, but non were all-welded.

RECORD ATTENDANCE AT ANNUAL ELECTRIC FURNACE STEEL CONFERENCE

Dinner Speaker C. F. Hood

A good technical program, fellowship, and an outstanding annual banquet drew a record crowd of 620 electric furnace steelmakers to the Eighth Annual conference. Technical sessions on Continuous Casting, Raw Materials, Melting Practice, Furnace Maintenance, Oxidation and Deoxidation Practice and Temperature Control drew electric steel production men from all the major plants in the country.

Gilbert Soler, acting as toastmaster at the banquet that followed the cocktail party, introduced the speaker of the evening, C. F. Hood, president, Carnegie-Illinois Steel Corp. Mr. Hood spoke on the development and importance of the electric furnace steels, with particular emphasis on current military and nonmilitary requirements for steels of the high quality possible through electric furnace practice. He described several of the applications for such steels, and stressed the severity of customer specifications.

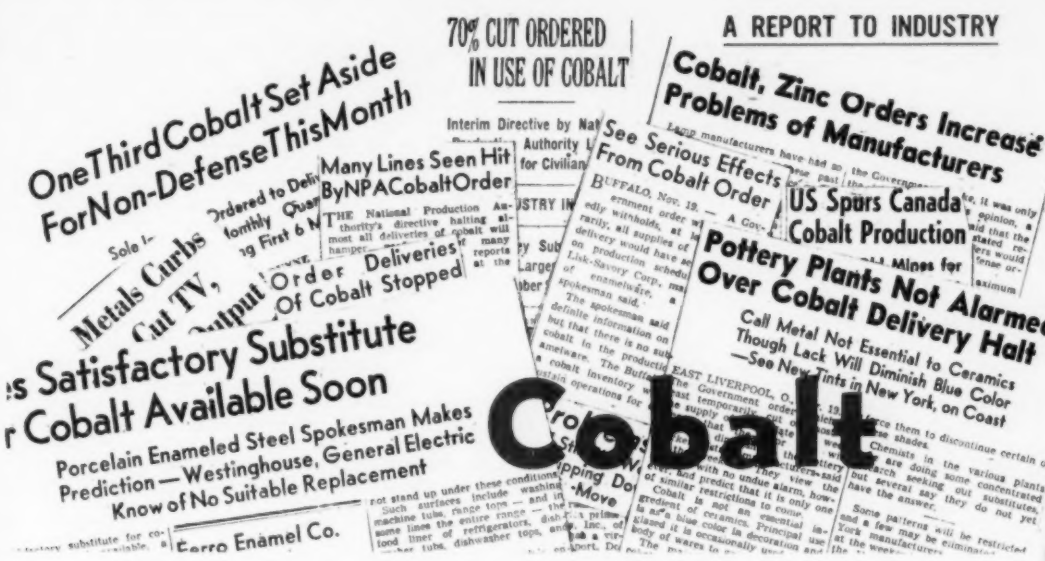
Officers elected to the Electric Furnace Steel Conference for the coming year include: T. J. McLoughlin, chairman of the Executive Committee; R. H. Frank, chairman of the Conference Committee; and Walter Farnsworth, vice-chairman of the Conference Committee.

The committees in charge of the eighth annual meeting included: J. A. Bowers, chairman of the Executive Committee; T. J. McLoughlin and R. H. Frank, chairman and vice-chairman of the Conference Committee; and D. B. Baxter, chairman of the Local Committee on Arrangements.

Seated at the speakers table are D. G. Baxter, Copperweld Steel Co.; J. E. Fick, Timken Roller Bearing Co.; H. K. Work, New York University; J. A. Bowers, American Cast Iron Pipe Co.; and T. J. McLoughlin, Carnegie-Illinois Steel Co.

Toastmaster Gilbert Soler

JOURNAL OF METALS brings to industry a timely and authoritative report on COBALT — consumption, uses, production, and supply prospects.


A REPORT TO INDUSTRY
70% CUT ORDERED IN USE OF COBALT
Cobalt, Zinc Orders Increase Problems of Manufacturers
One Third Cobalt Set Aside For Non-Defense This Month
Many Lines Seen Hit By NPA Cobalt Order
See Serious Effects From Cobalt Order
US Spurs Canada Cobalt Production
Pottery Plants Not Alarmed Over Cobalt Delivery Halt
Call Metal Not Essential to Ceramics
Though Lack Will Diminish Blue Color
—See New Tints in New York, on Coast
Metals Curbs Cut TV,
Deliveries Of Cobalt Stopped
Satisfactory Substitute
Cobalt Available Soon
Porcelain Enameled Steel Spokesman Makes Prediction — Westinghouse, General Electric Know of No Suitable Replacement
Cobalt
Ferro Enamel Co.

A Report to Industry on a Strategic Metal, Discussing Sources, Use Limitations, and Future Supply Possibilities. . . . By the Staff of JOURNAL OF METALS

BROMO Seltzer blue has gone to war. The blue of the Bromo Seltzer bottle is a product of cobalt, the Nation's No. 1 strategic metal. When the National Production Authority, on Nov. 21, 1950, ordered a 70 pct cutback in domestic use of cobalt, a stab of pain was felt in the hearts of the glass, porcelain enamel, steel, paint, pottery, and electrical and electronic equipment industries. The reason: A full-scale wartime economy with astronomical requirements for jet engines, high velocity projectiles, armor plate, electronic equipment, and the many products needed to win a war. There is little potential comfort for cobalt users in nonessential manufacturing, and the military will be pinched for optimum supplies of the metal. However, if proper measures are taken immediately and current plans are completed, in two years there will be far more cobalt available than ever before. When normal times return, cobalt supplies should be sufficient to meet peacetime military requirements, and greatly expanded domestic requirements that will result from new technological development for wartime but adaptable to peacetime products. The pres-

Drilling a vein rich in cobalt and silver preparatory to blasting in Silanco Mining & Refinery Co's. Temiskaming mine. Cobalt vein is shown by bloom in upper right hand corner.

ent crisis is a challenge to the mining and metallurgical industries.

The name cobalt, derived from the German *kobold* meaning goblin or something bad, was applied because the high arsenic content in the ore caused sores on miners' hands. Long before Christianity, cobalt was used as a pigment and to provide a hard, glossy surface to ceramics. Prior to World War I, cobalt consumption in the United States was low, and cobalt was imported from Canada as an oxide for the ceramic industry. Since 1922 the demand for the metal has increased steadily to about 8 million lb a year, as is shown in Table I, compiled from statistics in the Bureau of Mines *Minerals Yearbook, 1949*. Nearly all cobalt used in the United States is imported, and consequently these figures actually indicate consumption.

The ceramic industry is the oldest consumer of cobalt. It has been used classically to provide a blue color. It makes an underglaze or overglaze stain, which, when combined with the oxides of chromium, nickel, and manganese, yields all shades of blue or green. The blue of the Bromo Seltzer bottle is a familiar application of its use. It also counteracts the yellow stains from traces of iron in clays used for whiteware. About 1 lb of cobalt oxide per ton of dry body is used for this purpose. Cobalt oxide is used in frit or ground coats in porcelain enamelware because it enhances bonding at the steel-enamel interface. This consumption totaled about 424,000 lb in 1949, but only part of it is considered essential when wartime restrictions are in force.

Carbonates, hydroxides, acetates, and other salts of cobalt are used as driers in paints and varnishes. There are substitutes, but they are not effective. Much success has been achieved by using cobalt to supplement pasture deficiencies in cattle raising. Consumption of cobalt for these combined uses totaled 765,000 lb in 1949.

Imports of cobalt in all forms increased steadily in the two decades from 1920 to 1940. During the past decade, however, alloy and ore imports have varied and imports of oxides, sulphates, and other compounds have declined. Imports of the metal have increased phenomenally, the result of increased metallurgical use. The decline in imports of cobalt compounds is probably the result of their increased production in the United States from the ores and alloys imported. Table I illustrates these trends. Discrepancies between the figures for "Imported for Consumption" (Table I) and "Consumption by Uses" (Table II) is accounted for by consumer stocks and U. S. stockpiles. By the end of 1949 imports of the metal had reached over 5 million lb.

In 1941, it was first reported in the *Minerals Yearbook* that the largest single use of cobalt was in the production of Stellite-type alloys. Permanent magnet production now accounts for the greatest amount, and high-speed steels, hard-facing materials, and cemented carbides are large consumers. If figures on cobalt consumption are released in the coming months, it is likely that the refractory-type alloys used in gas turbines will be the largest single consumer. The impact of these alloys on cobalt supplies has not yet been fully felt.

Cobalt in high-speed steels improves cutting performance at high speeds and elevated temperatures. It is used in certain high-speed steels with tungsten, chromium, molybdenum, vanadium, and other alloying elements in amounts up to about 13 pct. Cobalt is desirable in many, and necessary in some of these high-speed alloys. Only a small percentage of high-speed steel grades, however, contains cobalt, 283,496 lb being used in 1949.

The big consumer of cobalt is in refractory-type alloy production, with 1,238,083 lb going into these products in 1949. Stellite is the trademark of the Haynes Stellite Co. for a group of alloys, used as refractory materials, cutting tools, and hard facing material. These contain 45 to 55 pct cobalt, 30 to 35 pct chromium, and 12 to 17 pct tungsten. Cemented carbides accounted for 118,522 lb of cobalt in 1949. Tungsten and other cemented carbides are sintered with 3 to 20 pct metallic cobalt as a binder. Both the Stellite alloys and cemented carbides are highly efficient heavy-duty metal cutting and metal die materials. They are used for drawing, extruding, and cutting all manner of substances from hard metals and ceramic ware to soft plastic materials, wood, and carbon.

Substitution of vanadium, tantalum, and boron for cobalt in high-speed steels are possibilities; and nickel can be used as a binder in cemented carbides but with impairment of efficiency. J. P. Gill, Vanadium Alloys Steel Corp., Latrobe, Pa., in 1942 suggested various substitutions for cobalt in high-speed steels. Four German patents have been reported for various hard cast-alloys which eliminate cobalt. These contain: W-B-Si; Mo-Mn-Cr: W-Fe-Ti-C; W-Fe-Ti-Ce. Substitutions, however, are not

Table I—Cobalt Imported for Consumption in the United States, Lb[1]

Year	Alloy	Ore	Metal	Oxide	Sulphate and Other Compounds	Gross Weight	Cobalt Content (Estimated)
1923 to 1924 Avg		43,753	172,296	242,639	23,220	481,908	354,500
1925 to 1929 Avg		158,315	467,080	366,045	47,758	1,039,198	752,200
1930 to 1934 Avg	x	323,072	307,232	374,091	67,347	1,071,742	655,200
1935 to 1939 Avg	x	621,487	1,117,829	653,486	60,466	2,453,268	1,679,000
1940	7,843,828	2,653,891	130,321	756,759	11,468	11,396,267	4,200,000
1941[2]	9,970,589	2,443,725	554,030	38,002	4,980	13,011,326[3]	4,328,000[3]
1942	10,313,867	834,797	148,304	———	200	11,297,168	4,280,000
1943	10,110,879	10,556,042	266,670	59,928	56	20,992,575	5,626,000
1944	8,500,516	473,529	73,088	225,609	115	9,272,857	3,798,000
1945	8,379,145	859,940	946,475	120,672	224	10,324,456	4,615,000
1946	1,648,593	657,787	1,935,582	1,074,630	350	5,316,944	3,451,000
1947	3,751,432	751,436	6,035,153	752,150	530	11,290,723	8,206,000
1948	4,879,413	8,167,545	5,266,521	790,300	1,374	19,105,153	8,821,000
1949	3,691,051	109,009	5,588,327	360,318	359	9,749,064	7,453,000
First ¾ 1950	2,888,178	116,757	5,283,294	629,999	1,414	8,919,642	6,610,695[4]

[1] Compiled from Bureau of Mines *Minerals Yearbook*.
[2] A small amount of alloy was imported in 1934 and 1935.
[3] In addition, 4,790,000 lb of Burmese speiss containing 335,721 lb of cobalt were imported.

always the answer because often the substitutions involve using one strategic metal for another. Practically speaking, none can be counted on to conserve cobalt.

Taking the lead in the postwar demand for cobalt are permanent magnets and magnet steels, production of which reached an all-time high in the first nine months of 1950, consuming 2,081,000 lb. The development of Alnico permanent magnet alloys accounted for a large percentage of this demand. Alnico 7, developed in 1949, was designed for high demagnetization force applications particularly in motors, generators and air-gap devices. Alnico 5 DG is used in loudspeakers and high field strength magnetic assemblies such as holding-magnet assemblies, magnetic chucks, and radar assemblies. It is also used extensively in television, and the 70 pct curtailment order has given that industry more to worry about than the controversy over color television. Other uses of the magnet are in communication, magnetic separators, and novelty fields. For instance, General Electric uses Alnico magnets on its new refrigerator doors so the harrassed housewife can close the door with her hip while holding a baby in one hand and a bottle in the other. This use is sure to go with the new restrictions.

The property of cobalt alloy magnets that makes them so attractive is that they are highly efficient. More magnetic energy may be stored in a unit volume of a cobalt magnet alloy than in any other alloy. Permanent magnet steels contain up to 40 pct cobalt with about 0.9 pct carbon. They may be cast, annealed, forged, machined, or otherwise shaped, and subsequently hardened and magnetized. It is almost impossible to find a substitute for cobalt in magnet steels, although some conservation may be achieved by using various complex steels having less cobalt, such as chromium-cobalt alloy.

Precipitation-hardening magnet alloys differ from the magnet steels in that they contain little or no carbon, are not magnetic *as-cast*, and are given the desired properties by precipitation of one or more of the alloying constituents from a solid solution under controlled conditions. These magnet materials can be prepared by powder metallurgical techniques. Although they represent the highest performance magnetic alloys known, they often are difficult to forge or machine. The precipitation-hardened magnet alloys offer several possibilities in substitutes for cobalt. Molybdenum and tungsten-chromium-molybdenum dispersion-hardened alloys can be substituted for low-cobalt magnets.

Chromium-cobalt magnet steels may be replaced by dispersion-hardened molybdenum or tungsten-chromium-molybdenum alloys. Tungsten-cobalt steels containing 17 pct cobalt may be replaced by precipitation-hardened alloys containing 6 to 10 pct cobalt and 16 to 19 pct molybdenum.

When mechanical forming is necessary, there are no substitutes for the 35 to 41 pct cobalt alloys. However, where the product can be cast to shape, Mishima-type alloys containing iron-nickel-aluminum, may be substituted for most of the above cobalt alloys. There is, however, no known substitute for cobalt in the extremely high performance alloys of the new Alnico types.

Table III shows the relative efficiency of cobalt in some magnetic alloys. In the table, BrHc is the product: Retentive Power of the Magnet times the Coercive Force to Magnetize it; and is roughly proportional to the magnetic energy that can be stored in a unit volume of magnetic material. The product BrHc divided by the Percent of Cobalt is used in the table to compare the relative efficiencies of the use of cobalt in the various alloys.

The reason for treating the subject of magnetic steels at length is because they are important in military mobilization. To take one example, magnets used in instruments of guided missiles frequently must be contained in an instrument case that is often no more than 1-in. diam. Where weight and space are vital, the cobalt-alloy magnet materials are indispensable.

The past decade has seen the development of the so-called refractory types, or high temperature alloys capable of maintaining strength at operating temperatures of 1600°F or over, and capable of resisting creep, wear, corrosion, and erosion. Over 40

Table II—Cobalt Consumed in the United States by Uses, Lb of Cobalt[1]

Use	1943	1944	1945	1946	1947	1948	1949	1950 (9m)
Metallic:								
High speed steel	399,736	361,437	335,059	224,049	223,148	289,391	283,496	165,168
Other steel	29,604	36,865	25,566	201,949	87,719	132,803	162,638	177,590
Permanent—magnet alloys	1,032,374	1,322,097	1,105,880	1,463,539	1,106,147	1,352,371	1,194,920	2,081,060
Soft—magnetic alloys							42,965	7,576
Cast Cobalt-Chromium-Tungsten-Molybdenum Alloys	2,041,409[2]	1,757,673[2]	1,387,796	526,504	941,087	1,196,608	1,238,083	1,307,180
Alloy hard facing rods and materials	70,068	89,061	31,293	53,874	71,545	116,313	82,965	110,546
Cemented carbides			206,189	45,100	51,917	85,314	118,522	87,087
Other metallic	186,664	233,782	318,967	81,988	99,476	115,255	116,344	150,491
Total metallic	3,759,855	3,800,915	3,410,750	2,597,003	2,491,039	3,288,055	3,239,933	4,086,696
Nonmetallic (exclusive of salts and driers)								
Ground-coat frit	80,504	116,884	173,428	412,766	607,316	613,745	424,051	430,113
Pigments	39,384	53,854	100,789	170,662	207,928	232,725	188,606	143,207
Other nonmetallic	35,415	17,459	25,920	39,596	51,439	66,699	84,336	33,501
Total nonmetallic	155,303	187,997	300,137	623,024	866,683	913,169	696,993	606,821
Salts and driers lacquers, paints, inks, pigments, enamels, glazes, feed, electroplating, etc. (estimate)				885,000	797,000	818,000	765,000	755,000
Grand Total	3,915,158	3,988,912	3,710,887	4,105,027	4,154,722	5,019,224	4,701,926	5,448,517

[1] Compiled from Bureau of Mines *Minerals Yearbook*.
[2] Includes cemented carbides.

such alloys have been developed and at least 13 contain cobalt ranging from 13 to 66 pct. The alloys were designed for components of gas turbines, jet aircraft engines, and turbo-superchargers. Table IV shows the analyses of various of these high-temperature alloys. Vastly greater amounts of cobalt will be required by expansion of military requirements, but as stated earlier the impact of consumption for this work has not been realized fully.

From the standpoint of military mobilization, cobalt is important, and in Washington circles is considered about the "hottest" strategic metal on the list. Cobalt used in dies and cutting tools for defense orders will receive priority. Hard surfacing materials and alloys containing cobalt for high temperature and erosion resistance will be critical. Uses of cobalt for surgical and dental instruments, and as a powder metal binder for electronic instrument parts will receive priority. In magnetic steels, cobalt will be essential where maximum efficiency and size and weight limitations are factors. All of these requirements will seriously strain available supplies; but restricting nonessential consumer use, substituting where possible, and developing cobalt ore bodies in North America and purchasing from abroad will ease the situation.

As shown in Table I, the annual requirements are about 8 million lb, prior to the present emergency. If appropriate steps are taken at least half of this amount can be supplied by commercial recovery of the metal from ores on the North American continent. However, before going into this hypothesis it is desirable to review the present world sources.

Cobalt Sources

Despite the fact that cobalt is produced in many countries, Belgian Congo, Northern Rhodesia, United States, Canada, and French Morroco account for 95 pct of the production. Iron pyrites contain some cobalt, often only 0.05 pct, and it has been recovered from deposits in Finland, Germany, Greece, Italy, Norway, Spain, and Sweden. Germany obtained cobalt from iron pyrites during World War II.

The world's largest producer is the Belgian Congo. One company, the Union Minière du Haut Katanga, accounts for all of the production from this country. This black oxide cobalt is a byproduct of the mining of oxidized copper ores. The property is operating at peak production since the expansion of concentrating and refining capacity and the reopening of the Ruashi mine near Elisabethville. Production statistics for 1950 are not available, but in 1949 it set a record production of 4350 metric tons of contained cobalt. The property of the Union Minière in the Congo consists of the Kabolela mine and cobalt concentrating plant. This mine carries higher values in cobalt than in copper but is past its peak production. At Kamoto there is another cobalt mine and ore-treatment plant. Mines and concentrators are also operated at Kolwezi and Kipushi, but these are cobalt-bearing high-copper ores. At Jadotville, the company has six single-phase electric furnaces for smelting cobalt-bearing ores and slags. This plant has a capacity of about 300 tons a month. The cobaltiferous red alloy from the electric furnaces is refined in two rotary furnaces; and the resultant crude cobalt, which is a white metal alloy containing about 43 pct Co and impurities of Cu and Fe, is shipped to plants at Niagara Falls, N. Y. and Oolen, Belgium. These refineries process the alloy to metal, oxide, salts, and driers. The plant at Niagara Falls is operated by the Electro Metallurgical Corp., a subsidiary of the Union Carbide & Carbon Corp., but is owned by the African Metals Corp., the selling company in the United States for Union Minière.

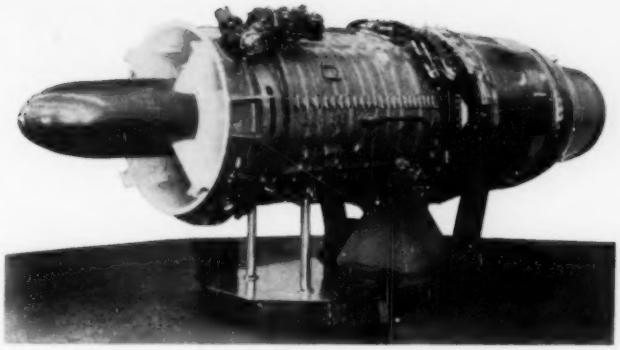
Table III—Relative Efficiency of Cobalt Utilization in Various Cobalt Magnetic Alloys

Type or Class of Alloy	Co, Pct	BrHc x 10^{-6} Gauss-Oersteds	BrHc x 10^{-2}/ Pct Co
Commercial steel, low cobalt	6.5	0.9	106
Commercial steel, Co-Cr	16.0	1.44	90
Commercial steel, Co-W	17.0	1.49	88
Commercial steel, 35 to 41 pct Co	38.0	2.28	60
Mishima, 17 pct. Ni; 9 pct Al	5.0	1.51	300
Alnico, 20 pct Ni; 12 pct Al	5.0	3.57	712
24 pct Co, 28 pct W dispersion hardened	24.0	1.42	59
6 pct Co, 19 pct Mo dispersion-hardened	6.0	2.04	340
12 pct Co, 19 pct Mo dispersion-hardened	12.0	2.52	210
Honda new KS, 16 pct Ni; 11 pct Ti	28.0	6.24	222
Fe_2O_3 + $CoFe_2O_4$, 1:1 by weight	12.5	1.35	108

The cobalt in the solutions used in the electrolytic copper plant at Jadotville is recovered by precipitation. The precipitates are treated by electrolysis in a refining plant capable of producing about 225 tons a month of high purity granules. The total annual refining capacity of the company's plants at Niagara Falls, Oolen, and Jadotville is about 7500 metric tons. Converted to pounds, this is equivalent to 9,587,400 lb of contained cobalt, of which 7,490,188 lb of oxide, metal, and alloy were shipped to the U. S. in 1949. For the first nine months of 1950, 6,597,425 lb of contained cobalt has been shipped to the United States. Since the Union Minière began production in the Congo in 1924, 36,706 metric tons have been produced. The first year's production, 1924, amounted to 273 metric tons. Between 1936 and 1937 production was more than doubled. Since 1937, when the output was 1500 tons, production increased steadily to the record year of 1949.

Prior to November 1950, there always have been adequate supplies to meet world demand. Most of this supply has been met by a single company, Union Minière. Since Apr. 1, 1949, the price of cobalt has remained steady at $1.80 per lb for 97 to 99 pct pure in kegs of 550 lb delivered east of Chicago. The United States has had excellent relations in regard to allocation of metal and price in dealing with Union Minière. There is no tariff on cobalt. Producing at the rate of 4000 metric tons annually, the company has sufficient reserves for 40 to 50 years proved and expects that additional development work will disclose more ore. The high cobalt ores are diminishing and the bulk of the shipped product will shift from the white metal alloy recovered from these ores to the granules recovered as precipitates from the solutions in electrolytic refining of high copper ores.

Recovery of cobalt from the cobaltiferous copper ores of Katanga is not complicated by the presence of nickel or arsenic. The cobalt-bearing copper concentrates are reduced in the blast furnace and part of the cobalt is in the slag, which is treated further. The cobalt that remains with the copper is recovered by precipitation. Fines from cobalt concentrates and slags are first sintered in a Dwight-Lloyd



Cobalt is an essential element in the production of jet aircraft engines, such as this British Armstrong Siddeley Sapphire, a 7200 lb static thrust turbo-jet engine.

sintering machine before charging into electric furnaces. Lime and nut coke are added to the charge. The metal tapped from the furnaces separates into two layers. The lower one is crude copper containing cobalt, which is treated in the rotary furnaces of the copper refinery. The upper layer is crude cobalt alloy. It is cast into ingots or granulated by pouring on a flat jet of cold water. The granules or ingots are sent to the United States or Belgium.

Rhokana Corp., in Northern Rhodesia, is the second largest producer of cobalt. The first significant production was 1,976,000 lb of alloy containing 1,018,000 lb of cobalt in 1934. In the years 1938, 1940, and 1942 to 1944 production of cobalt exceeded 2 million lb and in 1939, the record year, it was over 3 million lb. Production has declined since 1944 so that in 1949, 2,342,000 lb of alloy containing 886,000 lb of cobalt were produced. Production from Rhokana is consumed in the United Kingdom.

The cobalt-bearing copper minerals at the Nkana mine of Rhokana are almost entirely sulphides, with an average cobalt content of about 0.15 pct in the form of carrollite. Two concentrates are made, one high in copper and low in cobalt and the other high in cobalt and low in copper. These are treated separately in reverberatory furnaces. A sulphide matte containing copper, iron, cobalt, and sulphur is formed in the bottom of the furnace, while a slag layer is formed on top. The slag is waste and the matte goes to the converters. In the converters, silica is added to form a fluid slag. Cobalt oxidizes before the copper and is removed as a silicate in the slag together with iron and copper as oxides and sulphides and silicates of aluminum, calcium, and magnesium. The slag is granulated and sent to the electric furnace where an alloy containing copper, iron, and cobalt is produced. The alloy is granulated and is ready for shipment to the refinery. Increasing iron content of the ore encountered in deeper mining has necessitated retreatment of considerable quantities of alloy in the converters.

Laboratory and pilot-plant investigations on the production of electrolytic cobalt from a flotation concentrate have been in progress. As a consequence of these studies and a $550,000 grant from the Economic Cooperation Administration for plant expansion, it is expected that Rhokana production will be increased substantially in 1951.

French Morocco sometimes ranks third in the world production of cobalt. La Société Minière de Bou-Azzer et du Graara, Casablanca, is the sole producer. The Bou-Azzer ore body outcrops in pre-Cambrian strata, which form the substructure of the Anti-Atlas Mountains. The ore is found in small pockets but it is believed that there are larger ones. The cobalt minerals are smaltite and skutterudite. The average cobalt content is 11 to 12 pct, but there are other commercial deposits having only 0.75 to 1.25 pct. Gold is also recovered from the ore, in amounts of 5 to 30 g per ton. The ore also contains nickel and silver. Concentrates are shipped to Belgium for processing to oxide and

Table IV—Analyses of Cobalt High-Temperature Alloys, Pct

Alloy Designation	Co	C	Mn	Si	Cr	Ni	Mo	W	Fe	Other
Low Carbon N-155 Multimet	20.00	0.15	1.00	0.50	20.00	20.00	3.00	2.00	Bal.	N-0.14, Cb-1.00
Low Carbon N-155	13.00	0.15	1.50	0.50	16.00	15.00	3.00	2.00	Bal.	N-0.14, Cb-1.00
S-590	20.00	0.42	1.12	0.57	20.00	20.00	4.00	4.00	Bal.	Cb-4.00
S-816	44.00	0.40	0.62	0.57	20.00	20.00	4.00	4.00	4.00	Cb-4.00
K-42-B	22.00	0.05	0.70	0.40	18.00	42.00			13.00	Ti-2.00, Al-0.60
Refractalloy 26	20.00	0.03	0.70	0.65	18.00	37.00	3.00		Bal.	Ti-3.00, Al-0.30
Refractalloy 70	30.00	0.04	2.0	0.30	30.00	21.00	8.00	4.20	14.00	
Refractalloy 80	30.00	0.10	0.60	0.70	20.00	20.00	10.00	5.00	14.00	
Hastelloy B	2.00	0.05	0.60	0.25		65.00			4.50	
Vitallium	64.00	0.30	0.30	0.25	27.00	2.00	5.00		2.00	
Haynes Stellite 23	65.00	0.38	0.30	0.60	25.00	2.00		6.00	1.00	
Haynes Stellite 27	30.00	0.42	0.50	0.40	26.00	36.00	6.00		1.00	
Haynes Stellite 30	51.00	0.42	0.50	0.40	26.00	15.00	6.00		1.00	
Haynes Stellite 31	54.00	0.50	0.60	0.70	25.00	10.00		7.50	1.00	
X-40	54.50	0.45			26.50	11.00		7.25	0.60	
X-50	40.00	0.40	0.60	0.50	23.00	20.00		12.00	3.00	

speiss, which are exported to France where the speiss is refined to metal. After the German occupation of Morocco in World War II, the ore was shipped to the United States. ECA has made a contract to purchase 7200 metric tons of ore from French Morocco to be delivered by November 1952. This ore averages 12 pct cobalt and will be refined at Deloro, Ont. Production at Bou-Azzer began in 1935 and in 1938, 612,712 lb of cobalt were produced. In 1949, production declined to 460,636 lb.

Canadian Production

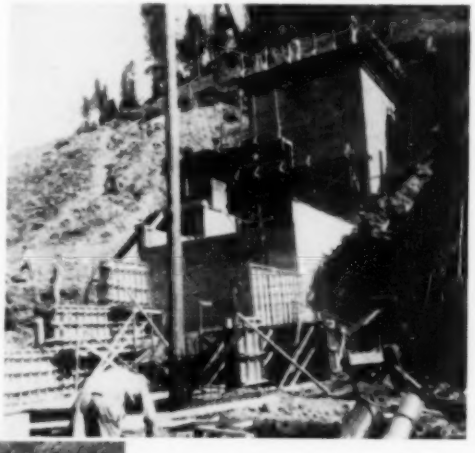
Canada has a history of cobalt production going back to 1904 when production from the fabulous Cobalt, Ontario, silver mines began. For three successive years, 1908 to 1910, production of cobalt metal exceeded 2 million lb; but it was not the cobalt that made this district prominent. Between 1904 and 1922, $300 million worth of silver was produced, which is the greatest production from one camp in such a short time in the world's history of silver mining. Today, the Cobalt district is being revived because of new silver discoveries in the old producing formation. Production of cobalt is tied up closely with the production of silver from these mines. High grade silver ores bearing cobalt are mined, but high cobalt ores with values in silver also can be produced. The problem is an economic one, because the miner does not get paid for the cobalt in the high silver ores and the price for cobalt, 80 to 85c per lb to the miner, is not high enough for him to mine the high cobalt ores. If the mining companies received $1.25 per lb for their cobalt or received payment for 85 pct of the contained cobalt in the silver concentrates, more of the cobalt-bearing ores would be mined.

At present, two mines are producing and milling ore, the Silver Miller Mines and the Cobalt Load Silver Mines; and 10 other properties are in the development stage. Deposits are fault fissure veins 4 to 5 in. wide, a few hundred ft long and usually less than 300 ft deep. Cobalt in the ore runs as high as 9 to 10 pct in the form of cobalt arsenides, cobaltite, and safflorite. Arsenopyrite and niccolite are also contained in the ore.

One of the main factors that held back recovery of cobalt was the absence of a smelter and refinery in the district. Concentrates were shipped to Deloro Smelting & Refining Co., Ont. There was not sufficient ore during World War II to keep the smelter operating and the smelter changed over to treat African ores. Concentrates from Ontario were stockpiled until a sufficient amount was accumulated to warrant operation of the smelter. In 1945, Silanco Mining & Smelting Corp. began construction of a smelter 1 mile south of Gillies, which was to have a daily capacity of 10 tons of concentrates, using electric furnaces for smelting and chemical treatment for separation of the copper, nickel, arsenic, and silver in the ores. The successor to Silanco, the Cobalt Chemical & Refinery Co. completed the smelter in 1949, but it burned down shortly afterwards. It is reported that the New Cross Chemical Co. plans to construct a plant adjacent to the smelter of Cobalt Chemical to produce salts, oxides, and other cobalt products.

As the situation now stands, the silver mines are perforce developing cobalt-bearing ore bodies, and there are probably considerable amounts of cobalt-bearing rock on the surface in mill tailings and waste piles. It is planned to reconstruct the burned out smelter. Cobalt Chemical & Refinery Co., has had a purchase order for $2,880,000 worth of cobalt from the United States Government since Dec. 5, 1949. One of the major difficulties in meeting the obligations of this contract has been in getting skilled technical assistance for solving the complicated metallurgy of recovering cobalt from these nickel-arsenic bearing ores. It is probable that 750,000 lb of cobalt could be produced annually from this area under proper conditions. These possibilities are being kept alive, receiving consideration in Washington circles, and a firm of well-known consultants has been retained to study production problems.

International Nickel Co. of Canada, Ltd. continued the recovery of cobalt as oxide at Port Colborne, Ont., refinery. This cobalt comes from the nickel-copper ores of the Sudbury district. In 1948, 15 short tons of oxide were produced and went to the United Kingdom. Expanded production is expected in 1952.



Work in progress at the Howe Sound Co's. Blackbird mine, Forney, Idaho. At left, the campsite in June 1947, and above, a recent picture of the coarse crushing plant under construction.

Falconbridge Nickel Mines, Ltd. continued work on a plant at its nickel refinery at Kristiansand, Norway, to produce cobalt oxide and electrolytic cobalt. This cobalt will be recovered from the matte produced from Sudbury nickel-copper ores. The plant is expected to be in operation in 1951.

Cobalt produced in Canada in 1949 amounted to 613,000 lb, as compared to 1,544,852 lb in 1948. The major portion of the 1948 output came from accumulations during the war years rather than from ore mined in 1948. Most of this production went to the United States.

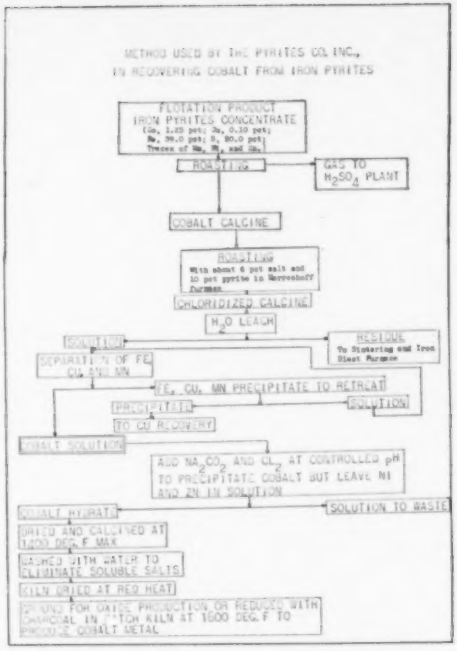
A cobalt-bearing ore body in Uganda, British East Africa, carrying 0.3 pct cobalt, 1½ pct copper and no nickel or arsenic, is reportedly under study by the interests of Ventures Ltd. and Rio Tinto Co. Ltd.

Burma production of cobalt was important to the United States in 1943 when 206,724 lb of speiss, which contained 7 pct cobalt, 30 pct nickel, 40 pct arsenic, and 10 pct copper, were imported. This speiss is still in the Government stockpile.

In 1948, the U.S. Government gave a contract to the Reduction & Refining Co. of Kenilworth, N. J. to recover cobalt from various ores and residues in the stockpile. Other countries have produced small quantities of cobalt, including Australia, New Caledonia, Bolivia, Chile, Finland, Italy, Japan and Sweden.

Despite the fact that the United States is the largest consumer in the world, only a small amount of cobalt is produced here. Bethlehem Steel Co. produced 673,773 lb in 1949. The cobalt comes from the iron pyrites that accompany the magnetite mined at Cornwall, Pa. The cobalt bearing material, averaging 1.3 pct cobalt in 1949, is shipped to the Pyrites Co., Wilmington, Del., where it is processed to metal and other cobalt products. Details of this process are shown in Table V. For the past 10 years this has been the only steady source of cobalt production in the United States. The Sullivan Mining Co., Kellogg, Idaho, has been recovering cobalt from the residues of its electrolytic zinc plant, but no shipments were made. In 1949, 10,000 lb were recovered.

Other companies and areas reporting small production of cobalt or development work on cobalt ore bodies include Eastern Magnesia Talc Co., Inc., Burlington, Vt., (recovered from talc); Cobalt Gold Mining Co., Boulder, Colo., (development work); Goodsprings district, Clark County, Nev. (development work on cobalt-copper ore body); property near Fort Thomas, Ariz. (small production); and Oregon, which has been credited with spasmodic shipments of arsenical ore containing cobalt, gold, and silver. A promising source of cobalt is from the properties of the St. Louis Smelting & Refining Co., near Fredericktown, Madison County, Mo. The company is a subsidiary of the National Lead Co. Prior to 1921 sporadic production on a small scale was achieved from the complex ore body which contains copper, lead, iron, and nickel, in addition to cobalt. Total output from Missouri did not exceed 700,000 lb. Large sums of money were spent on the development of metallurgical processing of the ore, but no process proved entirely satisfactory. In 1942 development of the ore bodies was undertaken and the U. S. Bureau of Mines made studies on concentrating the ore. Fairly satisfactory results were obtained by selective flotation of two concentrates, copper-lead and cobalt-nickel. Construction of a mill was started in 1943 and production began in July, 1944. A flotation process was used to make a lead concentrate,



a copper concentrate containing some lead, and a nickel-cobalt concentrate. The roasted nickel-cobalt concentrate contained about 19 pct nickel and 12 pct cobalt. Some of this concentrate was shipped to the Ferro Enamel Supply Co. of Cleveland, for chemical recovery of separate oxide products of nickel and cobalt. In addition to the roasted concentrate, some ore and calcines were produced and shipped to Pyrites Co., at Wilmington. Some commercial production of cobalt was achieved from 1944 to 1946. Production of cobalt was suspended in September, 1946, but studies on the recovery of cobalt have been continued. Recently, concentrates of cobalt-nickel sulphides have been stockpiled, as the Fredericktown ore body has been worked for copper and lead.

The Chemical Construction Co., a subsidiary of American Cyanamid, has developed a process through the pilot plant stage that will treat the Fredericktown flotation concentrates and carry on through the production of the metal. This process has not been disclosed yet, but will probably be announced in the spring of 1951. The Chemical Construction

Table V—Sample Analyses of The Pyrites Co., Cobalt Products

Cobalt Metal Element	Range, Pct
Co	98.50 to 99.00
Cu	0.02 to 0.06
S	0.01 to 0.04
Fe	0.06 to 0.16
Ni	0.15 to 0.40
Mn	0.04 to 0.06
CaO	0.10 to 0.40
C	Less than 0.10

Cobalt Oxide Element	Range, Pct
Co	70.00 to 71.00
Cu	0.08 to 0.15
S	0.04 to 0.18
Fe	0.07 to 0.10
Ni	0.10 to 0.50
Mn	0.02 to 0.10
CaO	0.07 to 0.35

Screen	Pct
On 65 Mesh	0.0
On 100 Mesh	0.5
On 150 Mesh	1.0
On 200 Mesh	10.0

Table VII. Refiners or Processors of Cobalt in the United States, 1950

Refiner or Processor	Location of Plant	Cobalt Product[1] Made	Cobalt Raw Material[1] Used
Advance Solvents & Chemical Corp.	New York	F	B
African Metals Corp.	Niagara Falls	A, B, C, E	G
Ceramic Color & Chemical Mfg. Co.	New Brighton, Pa.	C, D, E	B
W. S. Chase Driers & Chemical Div., Industrial Lining Engineers, Inc.	Pittsburgh	F	D
Ferro Chemical Corp.	Bedford, Ohio	D, E, F	B, D
Harshaw Chemical Co.	Cleveland	D, E, F	B
McGean Chemical Co.	Cleveland	D, E, F	B
Mallinckrodt Chemical Works	St. Louis	E	A
Nuodex Products Co., Inc.	Elizabeth, N. J.	B, D, F	B, D
The Pyrites Co., Inc.	Wilmington, Del.	A, B, C, D, E	G
Shepherd Chemical Co.	Cincinnati	C, E, F	B, C, G
Standard Oil Co. of Calif.	San Francisco	F	A
Frederick A. Stresen-Reuter, Inc.	Chicago	C, D, E, F	B, D, H
Witco Chemical Co.	Chicago	F	B

[1] Abbreviations: A, metal (rondelles, granules, powder); B, fines; C, oxide; D, hydrate; E, salts; F, driers; G, ore, alloy, or concentrate; H, carbonate.

Co. also has worked out the process for the Blackbird ore. Fredericktown could be counted on for ½ million lb of cobalt annually, once it gets rolling with the new process.

By far the best immediate United States prospect for large amounts of cobalt is the Blackbird mine of the Calera Mining Co., which is operating for Howe Sound Co., in Lemhi County, Idaho. The Blackbird district is in east-central Idaho about 20 miles west-southwest of Salmon. Cobalt was discovered there in about 1901, but there was little interest in the metal until 1917 to 1920. In 1920, the Haynes-Stellite Co. deposit was explored, and 55 tons of concentrates containing 17.74 pct cobalt were produced from 4000 tons of ore. From 1938 to 1941 the Uncle Sam mine was worked, producing about 3657 tons of ore from which copper, gold, and silver was recovered. The U. S. Bureau of Mines and the U. S. Geological Survey mapped and explored the district with diamond drill and bulldozer between 1942 and 1946. In 1943, Howe Sound Co. became interested and took an option on a group of claims. The exploration programs indicated large tonnages of ore and in 1945 Howe Sound began the Calera adit to explore the Chicago zone. Since then plans have gone forward to open the mine, and recovery of the metal from the ore is expected to commence in 1951.

The mineralized rock contains chalcopyrite, cobaltite, pyrite, pyrrhotite, and gold. Research work has been completed on concentrating the ore and recovering the metal. U. S. Bureau of Mines studies disclosed that the high sulphide ores were amenable to treatment by selective flotation, supplemented by low-temperature calcination of the cobalt-iron concentrate and reflotation of the cobaltite. The Howe Sound Co. plans to go ahead with a standard milling procedure, with the exception that flotation is preceded by long conditioning at elevated temperatures.

Table VI—Estimated Annual Available Supplies of Cobalt to the United States by 1953 If Proposed Program is Completed

Source	Cobalt, Lb
Belgian Congo	7,500,000
French Morocco	900,000
Blackbird*	3,000,000
Fredericktown**	500,000
Cobalt, Ont.	750,000
Total	12,650,000

* Calera Mining Co., of Howe Sound Co.
** St. Louis Smelting & Refining Co., of National Lead Co.

No calcination will be used. This special conditioning serves to sharpen the flotability differential between the chalcopyrite, cobaltite, and pyrite. In succession separate copper, iron, and cobalt concentrates will be made. The iron will go to tailing, the copper will go to the American Smelting & Refining Co. Garfield smelter; and the cobalt will go to a new plant being erected at Garfield. A new process developed by the Chemical Construction Co. for the treatment of the cobaltite concentrate as mentioned in connection with the Fredericktown project will be used to recover the cobalt metal.

Present plans call for production of cobalt metal by September 1951. Capacity will be 2 million lb per year, with the concentrator rated at 600 tons per day. Washington has asked the Howe Sound Co. to increase the production rate to 1000 tons per day, which would mean better than 3 million lb of cobalt per year. It is likely that this will go through although confirmation has not been made.

Surveying the general cobalt picture for the next two years, it is apparent that if the demands of the military for cobalt are not exorbitant, there will be adequate supplies for all essential manufacturing. Furthermore, by 1953 there should be enough production to meet normal consumer demand as well as military requirements. Barring submarine warfare in the Atlantic, 7½ million lb from the Congo can be counted upon. Nearly 900,000 lb a year is being purchased for the stockpile to be delivered by November 1952 from Bou-Azzer, Morocco. The production record of this district and potential reserves indicate that similar tonnages can be counted upon annually. About 3 million lb from Blackbird, ½ million lb from Fredericktown, and ¾ million lb from Cobalt, Ont. can be anticipated. Blackbird production is set at 3 million lb because this is the amount that will be produced pending certain Government guarantees. Negotiations are under way in Washington to procure cobalt from Cobalt, Ont., so that ¾ million lb by 1953 is likely. Table VI shows that 12½ million lb of cobalt would be available annually by 1953. Compared to the 1949 supply of 8 million lb, this is a liberal margin. Table VII shows cobalt refiners or processors in the United States.

The present emergency is stimulating production of cobalt and the development of adequate smelting and refining processes, which will be available to supply industry requirements when and if a normal economy ever returns. There will be many new commercial uses for cobalt following this period of armament, as occurred after World War II.

MINERALS from the Sea

by C. M. Shigley

MAN'S hope to develop power from the sea has not yet been realized, but the prospect of recovery of minerals from that mighty storehouse has long since become real. There have been recent large commercial projects for recovering elemental bromine and magnesium from sea water.

The total volume of the oceans is estimated to be 320,000,000 cu mi.[1] Although the salinities of the several seas vary somewhat, the average is approximately 35,000 ppm of dissolved salts, equivalent to 165,000,000 short tons per cu mi. The oceans of the world thus represent a storehouse of about 50 million billion tons of dissolved materials. The chloride ion represents 54.8 pct of the total salts, the sodium ion 30.4 pct, sulphate 7.5 pct, magnesium 3.7 pct, calcium 1.2 pct, potassium 1.1 pct, carbonate 0.3 pct, and bromide 0.2 pct. Although the sea is believed to contain at least traces of every element, these eight ions account for over 99 pct of the sea water salts; all other elements total less than 1 pct.

Since the sodium and chloride ions represent 85 pct of the dissolved salts and are the most easily extracted, it is not surprising that they have been involved in the first recovery on record. Sodium chloride, common salt, was undoubtedly the first compound to be removed from sea water and used by man. It is believed that salt was used by cave men at least 5000 years ago. Salt from sea water is mentioned in Chinese writings about 2200 BC. Aristotle in his *Meteorologica* wrote of the origin and usefulness of the salts of sea water, and described a method of unsalting sea water. The ancient Greeks, Romans, and Egyptians were familiar with production of salt by solar evaporation of sea water. Such salt recovery has been common in China, India, and Japan for many centuries, and still continues. Salt from sea water was produced on the Atlantic coast of North America about 1680 and on the Pacific coast in 1852. The Atlantic coast industry was short lived, but that on the Pacific coast has thrived to this time.

The production of crude soda and potash from the ashes of seaweeds was accomplished in Scotland as early as 1720. Iodine was recovered from sea weeds early in the nineteenth century; magnesia was first prepared on the Mediterranian coast at the end of the century. The records do not indicate any additional progress until 1923, when magnesium chloride and gypsum were produced from the bitterns from solar evaporation of the sea water of San Francisco Bay.[2]

These bitterns were first treated with calcium chloride, precipitating the sea water sulphate as calcium sulphate, which was settled, and filtered. Concentration of the filtrate, cooling; and separation of the residual magnesium sulphate, potash, and other salts by settling and centrifuging, gave a fairly pure magnesium chloride solution. This was further concentrated to saleable form by boiling. The calcium sulphate resulting from the calcium chloride treatment was washed, dried, and sold as gypsum.

In 1926, the first sea water bromine was recovered on a small commercial scale by chlorinating the San Francisco Bay bitterns, steam stripping, condensing, and purifying the product.

In 1931, the production of potassium chloride by evaporation of the waters of the Dead Sea was inaugurated. In 1932, bromine was recovered on a commercial scale from the residual liquors of the

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potassium plant, using a process similar to that employed for San Francisco bitterns.

Prior to 1933, the survival of the majority of the projects recovering material from sea water depended upon solar evaporation for initial concentration of the valuable sea salts. A few projects depended on adsorption or biochemical concentration, as in the production of soda, potash, and iodine from seaweeds. Of the other likely methods of recovery, precipitation by a specific reagent had been demonstrated in the commercial production of magnesia by liming sea water, and in the experimental removal of bromine as the insoluble tribromoaniline. The latter process was developed in 1924 by the Ethyl Gasoline Corp., and carried to large scale experimental work in the floating chemical laboratory, the *S. S. Ethyl*.[5] Separation by ion exchange processes or by selective volatilization of the material sought had not yet been commercially exploited.

In 1933, a sharp increase in the demand for ethylene dibromide as a constituent of gasoline anti-knock could not be met readily by increasing the output of bromine plants using subterranean brines. Based on experimental work done in anticipation of this need, a plant, shown in Fig. 1 at the top of the first page, was constructed by the Ethyl-Dow Chemical Co., at Kure Beach, N. C., to remove bromine directly from sea water, without the prior concentration which had been necessary for the earlier commercial recoveries. The significant feature of this operation was that the small amount of bromine was removed as a gas from the relatively large volume of water. Past efforts had been directed largely toward removal of large amounts of water as vapor from the relatively small amounts of dissolved salts.

Kure Beach Plant

The original Kure Beach plant was designed to extract 6,000,000 lb of bromine per year for the production of ethylene dibromide. Through minor additions and process improvements, the capacity was increased to nearly 9,000,000 lb per year. In 1937, the capacity of the plant was doubled, and in 1938, increased again, reaching an output of approximately 40,000,000 lb per year.

In 1940, a further increase in bromine requirements led to the erection of a plant, shown in Fig. 2, at Freeport, Texas, to recover bromine from the waters of the Gulf of Mexico. This plant had an initial capacity of about 30,000,000 lb of bromine per year and a second unit of equal output was built in 1943.

Another milestone in the recovery of minerals from sea water was passed in 1941, when at Freeport, Texas, the first magnesium metal was produced from water of the Gulf of Mexico by Dow Chemical Co. Although the precipitation of magnesium hydroxide from sea water bitterns and brines and the method of making magnesium metal from magnesium chloride were both well known prior to 1941, it was not until then that these methods were revised and integrated to give an economically feasible process for making metallic magnesium from sea water. The success of the first 18,000,000 lb per year magnesium plant, shown in Fig. 3, led to the erection of another plant of equal size one year later.

In 1942, a 72,000,000 lb per year magnesium metal-from-sea-water plant was built by the U. S. Government at Velasco, Texas, as a part of the program planned to meet emergency wartime needs. The plant was designed and run by the Dow Magnesium Corp. It operated at or above rated capacity for the duration of the war. That sea water represented no handicap as a source of raw material for the newly developed magnesium process was demonstrated by comparative costs published by the Defense Plant Corp., after cessation of hostilities.[6] The Velasco plant bettered by nearly 30 pct the lowest cost achieved by other Government plants using more concentrated magnesium sources.

Unfortunately, both the Government-owned magnesium project at Velasco and the privately-owned bromine plant at Kure Beach were among the war casualties when wartime production capacity encountered reduced peacetime demands. However, economic survival was largely in favor of the sea water processes. Since return to peacetime conditions, the entire United States production of virgin magnesium and an estimated 80 pct of the bromine have been derived from sea water.

The processes successfully used for bromine production at Kure Beach, N. C., and Freeport, Texas, and for magnesium at Freeport and Velasco, Texas, are chemically very simple. They have been described in detail in articles by Stewart,[4] Kirkpatrick,[6] Schambra,[7] and others.

There are two bromine extraction processes. Both can achieve recoveries of bromine approaching 90 pct from sea water. The first, called the "alkaline process," is used for the initial phases of the Kure Beach development. Sea water, which contains 69 ppm bromine, is screened carefully to remove debris, seaweed and fish, and is pumped continuously to the top of a "blowing out tower," a brick structure packed with wood grids. On its way to the top of the tower, it receives chemical additives that convert the non-volatile bromide of the water to relatively volatile free bromine. The first additive is dilute sulphuric acid, automatically controlled to reduce the pH of the sea water from 7.8 to 3.5 and thus suppress the hydrolysis of the free halides. The second additive is chlorine gas, which is injected in an amount slightly in excess of the equivalent bromide, converting it to free bromine. At the top of the blowing out tower, the treated brine is distributed evenly over the upper layers of wood packing, and trickles downward through the packing to outlet ports 40 ft below. As it slowly moves down, a current of air, drawn into the bottom of the tower by fans at the end of the system, passes up through openings in the grids and blows the free

Fig. 2—Bromine plant of Ethyl-Dow Chemical Co., Freeport, Texas.

Fig. 3—Magnesium plant, Dow Chemical Co., Freeport, Texas.

bromine out of the treated sea water. The latter passes back to the ocean at some distance from the intake, little changed except for its bromine content.

The bromine laden air from the top of the blowing out tower next passes to the soda ash absorption tower. This consists of nine spray chambers in series, each chamber having its own separate recycle system for spraying alkaline absorption liquor. Here, nozzles at the top of each chamber spray a dilute soda ash solution into the air stream. The sodium carbonate reacts with the bromine and puts it into solution as a mixture of sodium bromide and sodium bromate. Continued recirculation of the alkaline solution builds up the concentration of bromide-bromate, and at regular intervals the solution of highest concentration from the chamber adjacent to the blowing out tower is pumped to a storage tank. The charges of partially brominated alkaline solution in the other chambers are each pumped forward one step; and when the solution in the weak end of the system has been forwarded, the last chamber is recharged with a fresh 5 pct soda ash solution.

By means of this batch-countercurrent recirculation, a solution is obtained that is nearly 800 fold more concentrated in bromine than the original sea water.

Liquid Bromine

The production of pure liquid bromine from the sodium bromide-sodium bromate solution is accomplished by a second operation. The solution, which has a slight residual alkalinity, is pumped over a brick lined scrubber tower, where it serves to absorb bromine from the condenser vents. A small amount of steam is added to the bottom of the tower to preheat the liquor for the stripping step. A controlled excess of 60°Be sulphuric acid is then mixed with the liquor, and the reaction between sodium bromide and sodium bromate in the resulting acidic solution produces free bromine. The mixture passes to a continuous steam stripping column of acid proof construction. The bromine is distilled off, and, together with excess steam, is liquified in ceramic or glass condensers. The immiscible water layer, saturated with bromine, is returned to the stripping column. The bromine is purified by distillation, yielding elemental liquid bromine having a purity of 99.7 pct plus. The slightly acid stripping column effluent is added to the incoming sea water to utilize its relatively small acid content.

The second bromine process, known as the "acid process" or "SO_2 process," was developed in 1937, and has been used in all bromine from sea water plants built in the United States since that date. In this method, shown in Fig. 4, the acidification, chlorination, and blowing out of the sea water are carried out essentially the same as in the alkaline process. Into the bromine laden air from the blowing out tower is injected a carefully controlled flow of dilute SO_2 gas, prepared by burning sulphur and cooling the 10 to 12 pct SO_2 so obtained. The two gas streams are mixed thoroughly by passing through a system of carefully designed baffles, whereupon the bromine reacts with the slight excess of SO_2 in the presence of water vapor to give a mixture of hydrobromic and sulphuric acids, in the form of a fine acid mist. The acids are scrubbed from the air stream by fresh water in an absorption tower. The resultant acid solution has a bromide content of approximately 7 pct, or 70,000 ppm. This step thus accomplishes a 1000-fold concentration of the original bromine of the sea water.

The bromine is removed from the strong acid solution by a method similar to that employed in the alkaline process. The acid liquor is pumped over a packed column where it scrubs bromine from the condenser vents. It is preheated in that tower by the addition of live steam. Chlorine equivalent to 75 pct of the hydrobromic acid is added with the steam. The liquid mixture then passes to a steam stripping column, where the remainder of the equivalent chlorine is added, and the free bromine is steam distilled out of the solution. The bromine-steam vapor from the top of the tower is condensed as before, and purification of the liquid bromine so obtained yields a product of quality equal to that of the first described method.

The hot effluent from the stripping column consists of a mixture of hydrochloric and sulphuric acids. It is added to the incoming sea water, and under normal conditions supplies approximately two thirds of the acid requirements of the blowing out step.

The factors determining the competitive position of either or both of these sea water extraction processes differ only slightly from those encountered in the consideration of any economic enterprise. Principally, one must consider location, raw materials, efficiency of the process, materials of construction and manpower.

The proper location of a plant utilizing either bromine process is important to the success of the project. A place is required where sea water of high and constant salinity is conveniently available, free from organic contamination, and undiluted by major fresh water rivers. It also must possess favorable circumstances for disposing of the large quantities of processed water without mixing with the unprocessed water. Where shallow water and variable currents prevail, the intake and effluent systems should be widely separated. Deep water along shore and constantly favorable shore currents lessen the need for such separation. A plant site slightly above sea level is preferable to reduce pumping costs.

Since both processes depend on vaporization of bromine and since the vapor pressure of bromine in sea water varies considerably with temperature, a location in a warm climate is desirable. Other things being equal, a blowing out tower handling 25°C sea water can operate at a higher rate and

can produce approximately twice the amount of bromine as the same tower operating at 10°C. The absorption of the alkali process also is susceptible to temperature effects. Absorber losses are 5 to 15-fold more at 10°C than at 25°C, depending on the excess alkalinity of the absorbing solution. A location as near as possible to the source of economical raw materials and power, and to the point of disposal of the finished product, is desirable; but other factors are of secondary importance when compared with the need for favorable oceanographic and climatic conditions.

Because of the relatively large quantities of raw materials that must be handled to obtain each pound of bromine, it is necessary that close operational control be maintained at all points. Since reliable indicators and automatic controls have made a large contribution to the success of the large scale recovery of bromine from sea water,[2] they must be regarded as integral parts of both processes.

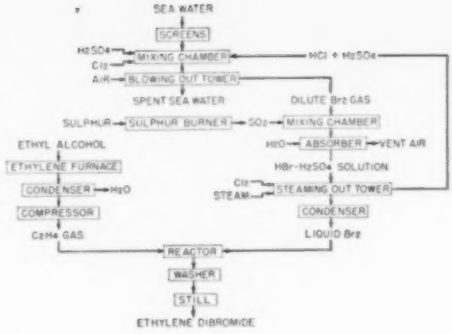


Fig. 4—Ethyl-Dow Sea Water Process Flow Sheet.

Magnesium

The manufacture of magnesium from sea water is quite different than bromine processes. Magnesium is taken out of the sea water in an alkaline condition instead of acid, and is removed by precipitation rather than blowing out, as in Fig. 5.

The process is carried out in ten well defined steps as follows:

1—Sea water containing 1300 ppm magnesium is screened as in the bromine process, and is continuously treated with an excess of milk of lime. The lime used in the present operation is prepared by calcining oyster shells at 1200° to 1400°C to produce chemical lime over 96 pct pure, slaking the lime hot, and settling the calcium hydroxide to a heavy slurry. An excess of 20 pct of the theoretical lime is necessary to keep boron compounds in solution. The boron of the sea water, if absorbed by the hydroxide and carried through the process, gives difficulty in the final electrolysis step. The limed sea water is delivered to standard Dorr settling tanks. There the precipitated magnesium hydroxide settles to the bottom and is drawn off as a thin slurry having a composition of about 12 pct magnesium hydroxide by weight. The overflow from the Dorr tanks is discarded, and represents nearly 98 pct of the water and other materials with which the magnesium was originally associated.

2—The slurry is filtered on Moore batch-type leaf filters, and about half of the remaining water and soluble materials are separated from the magnesium hydroxide. Filter cake containing 25 pct of magnesium hydroxide by weight is obtained.

3—The alkaline filter cake is neutralized, and then mixed with previously prepared magnesium chloride solution and agitated to make a slurry that can be pumped. It is transferred to a neutralizing tank where an automatically controlled stream of hydrochloric acid is added to exactly neutralize the magnesium hydroxide. Thus, a 15 pct magnesium chloride solution is obtained.

4—The magnesium chloride solution is evaporated to eliminate water and to reduce the solubility of salts picked up from the sea water. Evaporation is accomplished in either of two ways. In the earliest or direct-fired method, the magnesium chloride solution is sprayed into gas fired chambers. The more recent submerged combustion method accomplishes evaporation by burning a carburated mixture of natural gas and air below the surface of a pool of magnesium chloride solution. In either case, direct contact with the hot products of combustion concentrates the solution to 35 pct magnesium chloride by weight. Direct heating is necessary because of the scaling tendency of the solution.

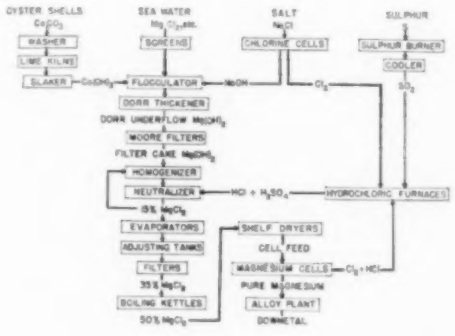
5—The unwanted calcium is precipitated from the solution by the closely controlled addition of magnesium sulphate. The treated liquor is held for 24 hr in an agitated tank to encourage crystal growth of the salt and gypsum.

6—The adjusted evaporator product then is filtered, first through Moore filters identical to those used earlier for the magnesium hydroxide filtration, and then through plate and frame presses for a final polish.

7—The filtered 35 pct magnesium chloride solution is evaporated to a concentration of approximately 50 pct. Open top, brick-lined steel boiling kettles heated by direct steam coils are used for this purpose.

8—The concentrated magnesium chloride liquor at a temperature of 170°C is transformed into a

Fig. 5—Flow Sheet of the Dow Sea Water Magnesium Process.



solid suitable for feeding the electrolytic cells. The hot liquid is sprayed on 6 to 10 times its weight of previously dried solid in a horizontal rotary mixer, producing a white granular material containing about 68 pct magnesium chloride. This is dried with hot recirculated air in a multi-shelf drier, similar in design to a Herreschoff furnace, and becomes a free flowing granular cell feed of approximate composition $MgCl_2 \cdot 1\frac{1}{2}H_2O$. Part of the dry granular material is returned to the rotary mixer, and part is conveyed to the magnesium cells.

9—This step is electrolysis of the cell feed.[7] The electrolytic cells used are bath tub shaped steel pots of approximately 2500 gal capacity, filled with a fused salt mixture consisting of 25 pct $MgCl_2$, 15 pct $CaCl_2$, and 60 pct NaCl, at 700°C. Graphite electrodes suspended in the bath serve as anodes; the pots and their internal baffles act as cathodes. Passage of a high amperage, direct current between the electrodes and the pot decomposes the magnesium chloride of the bath to elemental magnesium and chlorine gas. Cell feed is added continuously to maintain the proper bath composition and level. The hot gaseous products are collected under a tightly fitting refractory cell cover, cooled, and piped to the hydrochloric acid plant. The molten magnesium metal rises to the top of the bath, where it is trapped by inverted troughs and conveyed to the storage wells in the front of each cell.

The metal is hand dipped from the cells three times daily, and cast into the familiar 18 lb notched ingots. Each cell operating at 60,000 amp produces approximately 1200 lb of magnesium per day, having a purity in excess of 99.8 pct. No other refinement is necessary to meet the specifications for commercially pure magnesium.

10—The chlorine from the cells is converted to hydrogen chloride by high temperature reaction with steam and natural gas in a regenerative furnace. A small amount of unreacted chlorine is reduced by the controlled addition of SO_2 supplied by conventional sulphur burners. The hydrogen chloride and the small amount of H_2SO_4 are absorbed in water, and the resulting acid solution is recycled to the neutralizers for the reaction with $Mg(OH)_2$ previously mentioned.

Since process losses are inevitable, it is necessary to replenish the recycled hydrochloric acid to the extent of about ½ lb per pound of magnesium produced. This may be added as chlorine to the gas stream entering the furnace or as hydrochloric acid at the neutralizers.

Magnesium Uses

The properties and uses of magnesium are well known, but warrant brief comment. Magnesium is the lightest structural metal commercially available, one fourth as heavy as iron and two thirds as heavy as aluminum. Alloyed with small amounts of other metals such as aluminum, zinc, and manganese, it has a high strength: weight ratio, is easily fabricated, and has good corrosion resistance. These properties make it advantageous for use in lightweight structures and equipment such as airplanes, truck and trailer bodies, portable tools, hand trucks, ladders, and others too numerous to mention. The high place held by magnesium in the electromotive series of metals makes it outstanding for sacrificial anodes—in other words—sources of current for the protection of buried or submerged metal surfaces against corrosion. One of the more recently developed uses of magnesium is in the field of ferrous metallurgy. Small amounts of magnesium properly added to cast iron prior to pouring give a so-called nodular cast iron, which has strength and ductility properties similar to those of steel.

The economic factors involved in the magnesium from sea water operation are somewhat different than those of bromine. From an oceanographic or climatic standpoint, location is not as critical. The sea water that must be processed per pound of magnesium is only 5 pct that required per pound of bromine, and water temperature has little effect on the magnesium recovery. More important is a location favorable to the supply of raw materials and power. The convenient availability of lime, and abundant and inexpensive fuel and power obviously are essential for competitive operation.

The process can achieve a recovery of 85 to 90 pct of the magnesium in sea water. The performance of each step represents a compromise between high efficiency and high capital cost, and the justifiable recovery must be calculated for the conditions of each plant. The process has the inherent advantage that the majority of the materials can be conveyed by pumping. Most steps are continuous and subject to the benefits of automatic control.

In conclusion, the large scale recoveries of bromine and magnesium from sea water must not be regarded as merely incidents in the record of scientific progress of the past three decades. They are indicative of a pronounced trend toward using the seas for more of life's needs.

It is natural that this should be so. The seas cover three fourths of the earth's surface and, bordering upon every continent, represent a global source of supply. They are practically inexhaustible. Total quantities of available salts reach astronomical figures and are unquestionably increasing with the daily contribution of the rivers, while other mineral resources are being depleted. The handling of sea water by pumping is easier and cheaper than the majority of mining methods. The sea water has relatively stable chemical and physical properties, contributing to constancy of the finished product.

All these things, and more, lead to the inevitable conclusion that the record of past achievements, and the vision of man's increasing dependency on the oceans, will combine to stimulate the research activities of all the nations toward a more complete utilization of the tremendous resources of the seas.

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ALLOY STEEL PRODUCTION

In Large

Basic Furnaces

by A. K. Blough

THE rigid requirements placed on low alloy steels are a result of the constant efforts to increase strength-weight ratios of modern equipment. In recent years steel quality standards have gradually increased with service requirements. Only high quality electric furnace steels can pass consistently the strict tests imposed, particularly the magnetic particle test.

As steel quality has risen, the demand for production and furnace size has increased. Since larger furnaces and higher production rates make melting control more significant, electric furnace men continually must try to improve melting techniques. Melting practices must be maintained, which produce steels better than good enough to pass metallurgical quality standards.

Recovery of contained alloys in scrap is important. This is the most economical way to add non-oxidizable alloying elements such as Ni and Mo. Likewise, it is wasteful and harmful to charge scrap containing unwanted elements. For example, high residual chromium was found to have an undesirable effect on the cleanliness (nonmetallic) of chromium steels. The chromium spinels in the oxidizing slag made the slag viscous, difficult to work, and retarded oxidation reactions. Through proper charging, the Cr residual at meltdown is kept between 0.20 and 0.40 pct, and improvement in cleanliness results. Sulphur and phosphorus content should be low in electric furnace scrap. Tin is another undesirable contaminant. Currently, a heat that melts in higher than 0.01 pct Sn is rare, but the tin residuals are increasing and in the not too distant future may become serious.

The charge consists of about 35 pct heavy scrap, such as crops, about 45 pct medium weight scrap, and about 20 pct light scrap, such as low phosphorus plate or stampings. A typical charge for a SAE 4320 heat might be as follows: 45,000 lb of ½ pct Ni-Cr-Mo or 1¾ pct Ni-Cr-Mo crops; 40,000 lb No. 1 heavy melt railroad scrap; 20,000 lb Ni-Cr-Mo scrap from bar mill; and 30,000 lb low Phos light scrap or No. 1 bundles; a total of 135,000 lb.

The heavy crops or billets are charged first and are placed directly under the electrodes. The charge weight is from 130,000 to 140,000 lb in 60-ton furnaces. When possible, scrap is selected so that not more than two recharges are necessary. Long charging is conducive to dirty steel. Although the

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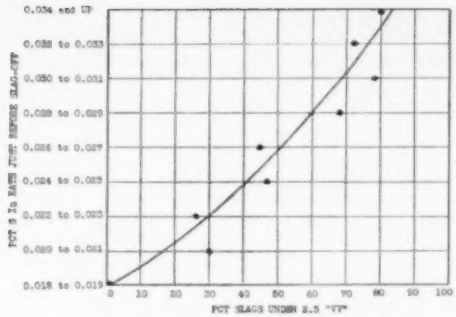

Fig. 1—Relationship between sulphur and V value.

reason for this is not thoroughly understood, it is probably caused by excessive oxidation and overheating between recharges. Ordinarily a 60-ton furnace can be charged with just one recharge. None of the furnaces at Canton Steel Div. are top charged.

In addition to scrap, the charge may contain coal, lime, and sinter, depending on the type of steel and practice involved. Coal is used on all alloy heats to insure a high enough carbon melt-in to allow the use of sinter. The coal is high grade anthracite and is added in pieces ½ to 1 in. diam, immediately on top of the heavy bottom scrap. Broken electrodes, if available, may be used in place of coal. Dead burnt lime is used rather than limestone since limestone retards melting because of heat absorption during calcination. The lime is high in effective CaO, containing about 94 pct CaO, 3 pct MgO, 1.5 pct SiO_2, and 0.01 pct S. Lime has a tendency to build up furnace bottoms, and is best added when scrap is almost melted. Magnetic sinter is preferred to hematite feed ore for electric furnace use. Sinter is lower in impurities, higher in contained iron, and will support the arc. Sinter, when used with the charge, usually is added near the end of the last recharge.

As the melt down proceeds, lime, fluorspar, and sinter are added to shape up the heat. A carbon-analyzer is used for early carbon tests to indicate the need for sinter additions. A lively boil should be attained to insure good slag-metal contact; and to aid in eliminating excess gasses, particularly hydrogen, and in eliminating some of the highly refractory oxides. The oxidation of C, Mn, P, and Si proceeds in the same manner as in the open hearth process. However, it should be remembered that all the oxygen added is in the solid form and oxidation can thus be rather closely controlled.

Once the charge has been melted completely, an early test is used to make preliminary adjustments of Ni and Mo. The nickel can be added as pure nickel or as nickel sinter (NiO). Nickel sinter is cheaper per pound of contained alloy and is preferred where large additions must be made. The nickel sinter supplies oxygen to the bath, and nickel recovery from sinter is from 97 to 100 pct, the loss, if any, being mechanical.

Molybdenum is added as molybdic oxide (MoO_3), which functions similarly to nickel sinter. Both the Ni and Mo are brought to within a few points of the desired analysis on these preliminary adjustments.

Sulphur is a never ending source of trouble. If there is much sulphur charged with the scrap, a high V-value ($CaO:SiO_2$ ratio) must be attained in the slag for S elimination. This relationship is shown graphically in Fig. 1. The spectrographic laboratory can determine quickly the V value and thus indicate the need for lime additions. If lime is added and sulphur reduced before slag-off, the refining period can be held to a minimum. On certain types of heats, present practice calls for a minimum V-value before slag-off. A number of reagents have been tried to aid in S removal and have been found little, if any, better than lime plus fluorspar. Among those tried were bauxite and fused Al_2O_3; and calcium carbide blown into the bath with argon under pressure.

When the P, S, and C have been reduced to the proper levels, desired nonoxidizable alloy adjustments have been made, slag is in shape, and the temperature is right, slag-off may begin. Green wood rabbles have been found best for raking slag as they are easy to handle, inexpensive, and readily disposed of after use. A clean job of slagging-off must be done to get the best results from the carbide slag. To aid in getting a clean slag-off, a large pusher rabble is inserted through the work door to push slag from the back of the furnace towards the charging door. The furnace is tilted slightly forward.

Just prior to the slag-off a metal test is sent to the laboratory to be analyzed for all expected elements. The slag-off itself requires from 10 to 20 min, depending on the amount of slag and the speed of the helpers. When the slag is drained, a reboil is added to the bare bath. This consists of 600 lb of silicomanganese for heats under 0.30 pct C, or 500 lb of regular manganese for heats 0.30 pct C and over. By this time test results are back from the laboratory and adjustments of C, Ni, and Mo are made to the bare bath. The carbon is brought to within 5 to 10 points of specification by addition of petroleum coke. The amount of coke added depends on expected pick up from the carbide slag and the amount of carbon going in with ferroalloys. About 80 pct of the petroleum coke is recovered as carbon in the bath. Ni is added as electrolytic sheet nickel and Mo as ferromolybdenum or molybdic oxide. It is sometimes more convenient to wait until later to add the Ni and Mo.

The refining period under the carbide slag permits the production of high purity electric furnace alloy steel. Alloy steels can be made using a single slag practice in the electric furnace, but such steels are merely comparable in quality to openhearth steel and the cost of production is higher. The calcium carbide in a carbide or reducing slag reacts with the oxides in the slag. When reduced, the oxides in the metal rise to the slag in an effort to maintain equilibrium conditions. Thus, the metal as well as the slag is deoxidized and the steel is purified.

The method of adding and shaping up the carbide slag has been the subject of much research and controversy. Most of the lime and fluorspar is premixed in a charging box outside the furnace. For a 60-ton heat, about 1500 lb of burnt lime and 500 lb of fluorspar are mixed in thin layers. This intimate mixing seems to aid quick fluxing of the lime upon addition to the furnace. When this slag base is in the furnace and power is back on, the operators begin to shape up the slag. More lime and spar, plus coke breeze and sand, are added as needed. The amounts of ingredients used in the slag are:

Burnt lime, 2200 to 2700 lb; Fluorspar, 600 to 1000 lb; Coke breeze, 300 to 500 lb; and Silica sand, 150 to 250 lb.

Variations in amounts of ingredients are caused by such factors as thoroughness of slag-off, C and S contents of the bath, and methods of the individual operator. A typical carbide slag analysis is about 20 pct SiO_2, 60 to 65 pct CaO, 2 pct Al_2O_3, 10 pct MgO, 0.15 pct MnO, 0.50 pct FeO, 0.50 pct S, 0.02 pct P, and 2.0 to 2.5 pct CaC_2. Samples checked for CaC_2 must be analyzed soon after being taken from the furnace, since the CaC_2 decomposes on exposure to moisture, forming acetylene. Small amounts of silicon carbide, about 100 lb in a 60 ton heat, have been found beneficial in speeding shape-up of the slag.

Table I. Temperature Specifications

AISI Type	Slag-Off Aim, °F	Tap Aim, °F	Tap Range, °F
E-5xxx	Over 2930	2780	2780 to 2810
E-8xxx	" 2930	2860	2850 to 2880
E-3xxx	" 2960	2890	2880 to 2910
E-1xxx	" 2930	2860	2840 to 2870

Once the heat is under the carbide slag, it is desirable to complete deoxidization, make additions, and tap as rapidly as possible. Studies have shown that FeO in the bath is reduced to a minimum about 60 min after the end of the slag-off period. Therefore, prolonged holding after this 60 min is a waste of furnace time as far as deoxidization is concerned and is a liability for H_2 absorption. Since the FeO in the bath is inversely dependent upon the C content of the bath, the minimum FeO for a 1 pct C steel is very low.

The sulphur in the bath is removed under the carbide slag by the reactions:

$$2\,CaO + CaC_2 + 3\,FeS \rightarrow 3\,CaS + 2\,CO\uparrow + 3\,Fe$$

$$2\,CaO + CaC_2 + 3\,MnS \rightarrow 3\,CaS + 2\,CO\uparrow + 3\,Mn$$

A problem was encountered in making some modified SAE 4620 heats with a sulphur specification of 0.008 pct max. The practice finally adopted was to reduce the S to 0.012 to 0.013 pct under the oxidizing slag by continually flushing off and adding more lime and spar. The final sulphur content of 0.007 to 0.008 pct was reached under the carbide slag, which consisted of about 3000 lb lime, 2000 lb fluorspar, 200 lb calcium-silicon, and 250 lb coke breeze. From this, it is evident that S may be brought to low levels under the carbide slag.

Final adjustments are made to the bath when a good carbide slag has been formed. The alloys used must be of high purity to avoid introduction of harmful impurities to the bath. Alloys must be clean both macro- and microscopically. Final carbon additions are made by using low phos pig iron, which contains about 0.025 pct P and 0.030 pct S.

Temperature has been mentioned briefly, and since temperature can make or break a heat of steel, this factor merits consideration. Excellent results have been experienced using an immersion pyrometer, consisting of a platinum vs platinum-rhodium couple encased in a refractory protecting tube with a silica tip. Each heat can be made to definite temperature specifications by using this instrument.

It is desirable to have a falling temperature from slag-off to tap. This condition gives better cleanliness from a nonmetallics standpoint. Alloy additions chill the bath, and if the temperature is not high enough at slag-off a large amount of power must be supplied to arrive at the proper tapping temperature. In addition, a temperature of 1540°C (2804°F) is necessary to form CaC_2 and it is best to have the slag-off temperature above the tapping temperature to keep the refining period short. On some heats, the temperature is taken at slag-off, before the chromium addition, before the silicon addition, and at tap to insure proper temperature progress. Some typical temperature specifications are shown in Table I.

By comparing magnaflux test results on a series of 4340, 4140, 4350, 3140, and 4130 heats it was found that the average tapping temperature was 2860°F on the good heats, and 2880°F on the poor heats. Although only 28 heats were involved in the study, the difference was shown to be significant by statistical analysis. These results illustrate how important temperature can be in producing quality steel.

As stated previously, the production of quality steel is the prime requisite of any electric furnace practice. It was found desirable to try to predict in advance which heats would be of such poor quality as to require retesting or rejection so that these heats could be followed closely through further processing. A point scoring system for unfavorable conditions was developed for certain types of steel, and this system proved to be 60 pct accurate in predicting bad heats. The scoring system is outlined because, with modification, it is applicable to most types of electric furnace alloy steels.

Score 2 to 6 Points:

Ladle S, 0.019 pct or over.
New ladle.
Dirt: hot top, mold, ladle.
Slag-off chrome over 0.39 pct.
Low "V" value in oxidizing slag.

Score 3 to 9 Points:

Tap and pour temperature, outside range.
S trouble.
Mn hop over 0.02 pct from slag-off to ladle.
Low slag-off temperature.
Temperature high too long.

Score 6 to 14 Points:

Bottom trouble.
Slag-off C over 0.30 pct below final.
Melt down over 4½ hr.
Cold furnace over 2½ hr.

The sum of unfavorable factors resulted in retests for various sizes of rounds as follows:

Size of Round, In. Diam	Point Score
5	Over 0
4½	Over 6
3¾	Over 15
3	Over 16
1¼	Over 25

These are some of the general and particular principles and practices of large scale electric furnace alloy steel production. The introduction of new raw materials, alloys, and facilities no doubt will create better and cheaper steels in the future.

Industrial Hygiene At American Smelting and Refining Company

by John N. Abersold and K. W. Nelson

INDUSTRIAL hygiene has been defined by Patty[1] as "the science and art of recognizing, evaluating, and controlling potentially harmful factors in the industrial environment." This definition implies thorough study of operations, evaluation of potentially harmful factors through air sampling, microanalyses and other means, and, finally, appropriate medical and engineering control wherever indicated.

The prevention of industrial health injuries is a vital part of operations of American industry today. Progress and interest in this field has increased steadily for many years, the most rapid progress having been attained, perhaps, during the last three decades. It is significant to note that there are now official agencies in 46 states actively concerned with industrial health problems and that a western field station has been established recently in Salt Lake City by the U. S. Public Health Service to augment its industrial hygiene services directed from headquarters of the National Institute of Health, Bethesda, Md. Many of the larger industries have found it advantageous to establish their own industrial hygiene departments.

The American Smelting and Refining Co. is a world-wide organization engaged in the mining, smelting, and refining of lead, copper, zinc, silver, gold, by-product metals, including cadmium, arsenic, and others. In the United States there are 13 smelters and refineries, 11 secondary smelters or foundries, and a number of mines. Approximately 9000 workers are normally employed.

It has long been the established company policy to seek out occupational hazards and provide safeguards for employee health. Protective equipment has been supplied to individual workers and exhaust ventilation installations have been in use in some operations for more than 40 years. All of the major units have their own medical departments which provide employees with excellent medical and hospital care.

In 1937 full scale industrial hygiene studies were undertaken at the Selby Plant and were extended to most of the other smelters during the next three years. In 1945 the Department of Hygiene was organized with Professor Philip Drinker of Harvard University as Director and with Dr. S. S. Pinto as Medical Director. The department is responsible for coordinating and maintaining a program for the good health of all employees from top management down to the lowest paid day worker. It is essentially a service organization serving all of the United States plants regardless of location or size. Full and part-time physicians employed in all of the company's American plants and working in close cooperation with the Medical Director are responsible for determining the state of health of all the employees and giving treatment when necessary. In general, medical care is confined to accidents or illnesses occurring while the men are on the job. Among the duties of the doctors is the making of careful physical examinations of new employees and routine check-ups of old employees.

In addition to medical care a primary responsibility of the department is the *prevention* of occupational illnesses. In this the main concern is with the working environment in relation to its effect on the worker. Environmental factors may be dusts, fumes, gases, toxic materials, heat, humidity, radiation, or noise. The objectives are: (1) Immediate control of these factors through the education of the worker, through providing the wearing of respirators or other protective devices, and through careful medical examinations and regular analysis of urine specimens; (2) a long range control program which may be accomplished by local exhaust ventilation, wetting of materials, changes in metallurgy, changes in methods of handling, or by use of special devices and special equipment.

To accomplish these objectives a fine industrial hygiene laboratory was built in Salt Lake City and equipped to do routine and experimental work. Trained and experienced industrial hygienists obtain the facts by making frequent hygiene surveys. These surveys include tests of the air, studies of all processes, and careful investigation of ventilation, lighting, and general working conditions. Except in emergencies, the air contaminants and often the substances handled by the worker are sent to the laboratory for analysis by chemists and technicians specially trained in industrial hygiene methods. The findings are evaluated in terms of limits recommended by various State and Federal agencies, and in light of all available medical data.

The methods used for studying the working environment involve all of the usual chemical and physical procedures employed in industrial hygiene. The Impinger, electric precipitator, thermal precipitator, and filter paper sampler have been used to collect atmospheric dust and fume samples. Of special interest here is the filter paper sampler, shown in Fig. 1, which was developed by Dr. Silverman at Harvard University. The instrument has been improved and is used very extensively in field studies. A water manometer connected behind an orifice is used to determine the rate of air flow. Calibration is effected by use of a standard gas meter or rotameter. The dust or fume is collected on a filter paper clamped between two rings, as shown in Fig. 2. The filter paper, such as Whatman No. 52, collects both dust and fume with a very high efficiency. The instrument is very convenient and easily transported.

The solids collected on the filter paper are analyzed in the laboratory usually by use of a polarographic procedure. By this procedure it is possible to measure quantitatively in a single analysis the

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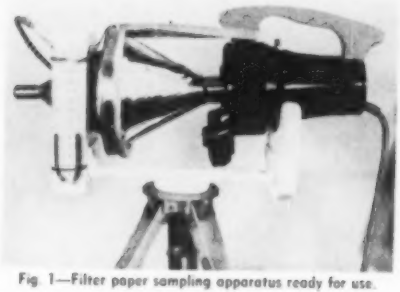

Fig. 1—Filter paper sampling apparatus ready for use.

copper, lead, cadmium, and zinc in each sample. Polarographic methods are also used for the determination of a number of other elements.

Dusts of various types are the most common contaminants found in the atmosphere of the various plants. Fumes containing lead oxide may be found in certain smelter and refinery work areas and are given special attention since lead oxide is more readily absorbed than other less soluble lead compounds, such as the sulphide. Other contaminants such as carbon monoxide, hydrogen sulphide, sulphur dioxide, selenium, tellurium, cadmium, and arsenic may be found and require study. Certain of the gases mentioned may be toxic or irritant. In order to be constantly on the alert and to be warned in advance, rapid field tests have been developed for hydrogen sulphide, chlorine, and arsine from a basic British method. In this method a small hand pump is used to draw air through filter paper disks impregnated with various reagents which produce a stain if traces of gas are present, see Fig. 3. These stains are compared with standards to estimate the gas concentrations. By use of this method chemists and safety directors are able to check the working environment for suspected dangers. For one plant where hydrogen sulphide is being used in one of its operations, a machine is being developed to sound automatically an alarm before any escaping gas reaches dangerous concentrations.

From time to time certain analyses requiring highly specialized training or very expensive equipment are performed by the research laboratory or outside laboratories; for example, spectrographic and petrographic analyses. Certain types of research work involving animal experimentation have been performed through grants to Harvard University.

As a part of the fact-finding function of the Hygiene Department, urine specimens and frequently blood specimens are obtained from all workers exposed to lead and other metals and examined at the Hygiene Laboratory. These tests indicate what the worker has been breathing, usually long before illness occurs. During the past year more than 5000 determinations for lead in urine were made. On the basis of these and other medical findings, the Medical Director may make recommendations for immediate protection of the employee.

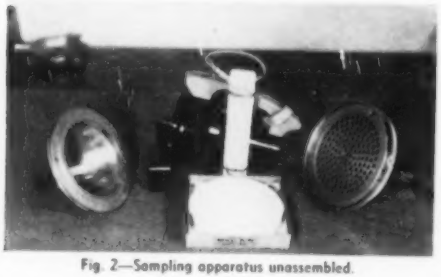

Fig. 2—Sampling apparatus unassembled.

The evaluation of all findings is an important function of the Hygiene Department. This involves in part an appraisal of air studies and the correlation of these studies with medical data. When all the facts are brought together, an overall evaluation of the environment is made, the need for control measures determined, and a coordinated control program outlined. Recommendations for control are made to the plant manager and passed on to engineers especially trained in industrial hygiene ventilation. The plant manager and the superintendent with his operating staff decide what method of control should be carried out. This is logical because control may be accomplished by changes

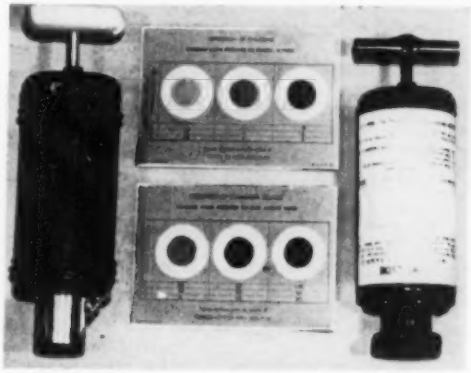

Fig. 3—Sampling pumps and standard stains for field determinations of hydrogen sulphide and chlorine.

in metallurgy or methods of handling rather than by local exhaust ventilation or other engineering or chemical means. Occasionally control is not possible by engineering means and it is necessary to rely on respiratory protective devices and medical control procedures. Sometimes the recommendations for plant improvements are based on comfort alone rather than a health hazard.

The ventilation engineers form a unit or a division of the Western Engineering Department but work in the closest cooperation with the Hygiene Department in carrying out the detailed recommendations. Frequent conferences are held with these engineers and general plans are approved.

Plant Improvements

Elimination or control of all potentially harmful factors in the environment is the major long-range objective. Since 1938, and particularly during the past four years, much progress has been made toward this objective. In some cases, such as in the mills, the cost has been very high—from ten to twenty thousand dollars per worker. Following are some of the highlights of control of dusts, fumes, and gases in the various plants achieved through the combined interest and effort of managers, superintendents, metallurgists, foremen, the specially trained staff of ventilation engineers of the Western

Engineering Department and the Department of Hygiene:

Mills: Wetting has long been used to control dusts in mills. However, because wetted materials in some cases clog up screens and chutes and hinder proper cleaning of equipment between ore lots, other means of control have had to be used also, chiefly local exhaust ventilation and dust collection by small baghouse units and centrifugal impingement washers. Because of the very high cost, experimental work has been conducted to find other methods. Mist-sprays produced by atomizing water with compressed air have been tried. The minute droplets of water produced by these sprays actually wet dust particles and help to reduce the escape of dusts at the source, yet they avoid objectionable wetting of the flowing material. With this method of control a 50 pct reduction in dust concentrations has been achieved in one mill.

In certain instances protection of the worker has been accomplished by ventilating and air conditioning small areas where men work, such as crane cabs, when the general ventilation of the room would be difficult if not impossible, see Stevenson.[2] In other words, the man has been "ventilated" instead of the operation. Cabs of cranes handling ores, carrying hot metals over furnaces, etc., are examples. This approach is being tried now in mills by building booths kept under positive pressure with filtered air for workers whose duties can be carried out from such an enclosure.

Sampling Rooms: Local exhaust ventilation and good housekeeping have been used exclusively to control dusts in sampling rooms, see Fig. 4. Modern grinding and sampling equipment are easily enclosed and the dust can be controlled at a very moderate cost.

Beds and Charge Bins: Wetting, enclosure and local exhaust ventilation are being used for control of dusts in such equipment. Dust control in these departments is one of the most difficult problems. Wetting can only be used to a limited degree because excess moisture may affect the roasting of certain types of charges.

The unloading of truckloads of ores and concentrates for storage or making up charges was a difficult problem to control in one plant. The final solution was found in a semi-enclosure and hood with high volume air intake.

Fig. 4—Ore sample being screened at bucking table with use of exhaust ventilated hood.

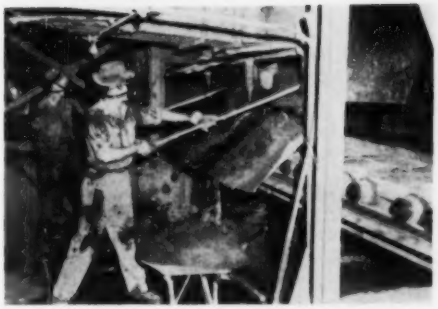

Fig. 5—Workers removing wetted dust from wind boxes of a first-over Dwight-Lloyd sinter machine.

Dwight-Lloyd Sinter Plants: Wetting, enclosure and local exhaust ventilation have been the principal methods of controlling dust and fume in the Dwight-Lloyd sinter plants. Water may be added to both first and second-over charges at the belt tripper, at the mixing tables and sometimes with use of pug-mills. Water is used to quench the sinter after it is roasted and the discharge ends of the machines are kept tightly enclosed.

The control of dusts from crushing first-over sinter has been effected with local exhaust ventilation and collection of dusts with centrifugal impingement washers.

The dustiest Dwight-Lloyd operation is the removal of deposits from wind boxes. Control of these dusts has been effected by (1) use of enclosed pan or screw conveyor along wind boxes with draft maintained on the boxes, (2) wetting by inserting into the dust piles a water pipe with flowing water and (3) maintenance of a water seal in the bottom of the wind boxes which completely wets the accumulating dusts. In Fig. 5 is shown the absence of visible dusts after wetting with inserted water pipes. The water seal has been applied only to second-over machines.

Good housekeeping with frequent wash down of floors is very important in control of dusts. Thermal air currents plus vibration can redisperse settled dusts.

Considerable improvement in dust and fume concentrations was effected in one Dwight-Lloyd plant by a change in metallurgy, that is, a lowering of the percentage of coke in the charge.

Excessive heat has been controlled by insulating wind boxes and air ducts and by use of large hoods mounted over the pallet immediately behind burners and connected to a stack for gravity ventilation.

Lead Blast Furnaces: The make up of blast furnace charges may involve dusty operations if the second-over sinter is not sufficiently wetted. The sinter is usually stored in hoppers and it has been found necessary to provide exhaust ventilation when the sinter is withdrawn.

The control of dust and fume at the feed to the blast furnace is accomplished chiefly by good draft on the furnace.

The lead blast furnace cannot be tapped for slag, or for lead if the temperature is high, without the generation of much lead fume. Fume from these points is controlled with local exhaust ventilation at all furnaces. It is necessary to raise and lower these hoods occasionally and workers have sometimes neglected this duty because of the little extra work

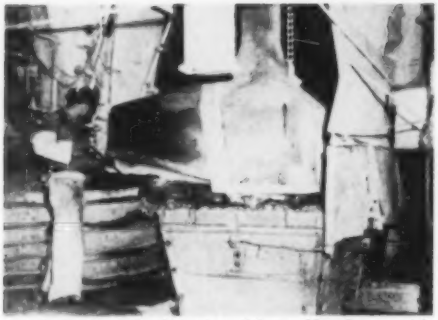

Fig. 6—Lead and slag being tapped from a blast furnace with use of an improved exhaust ventilated hood.

required. To overcome this and provide heavier construction to resist the heat, a hood has been very recently designed which can be raised and lowered by an electric motor merely by pressing a button as shown in Fig. 6. Stand-by empty or filled lead pots sometimes cause considerable fume. To control this an exhaust ventilated hood with a flexible fireproof duct has been developed.

Reverberatory Furnaces: Control of dust and fume from operation of lead dross reverberatory furnaces has been effected by adequate draft on furnaces to prevent escape of fume at the charge door and by local exhaust ventilation at the tap holes and launders for speiss and matte.

Kettles: One of the most difficult problems has been control of dusts and fume from refining operations in kettles. Complete or partial hoods with exhaust ventilation have been effective where metals are transferred to kettles or when stirring is done to separate drosses. Fig. 7 shows a partial hood with a high volume air intake to control the fume over the surface of a lead kettle. As another approach to reducing dustiness during dross skimming, experimental work is now under way to (1) change the metallurgy, (2) remove drosses with a screw-type conveyor with local exhaust ventilation at point of discharge into skip and (3) use of a high velocity slot type exhaust around edge of kettle. A fair degree of success has been achieved with use of the screw-type conveyor.

Flues: The removal of settled dusts from flues has long been a dusty and unhygienic operation. To control the dusts from this operation, engineers and metallurgists from the Federal Plant[3] developed the telescopic tube device shown in Fig. 8. This device serves as an enclosure and wetting chamber combined. A circular water spray located near the top partially wets the dusts as they pass from flue to car. The wetting of the dusts is continued in the car and minimizes dusting in later handling.

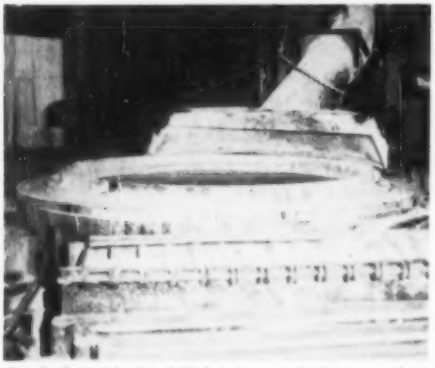

Fig. 7—Partial hood with high volume air intake over a lead kettle for control of lead fume.

Cottrells: The control of atmospheric dusts resulting from the cleaning of cottrell hoppers has been difficult. Enclosed and ventilated conveyors along hoppers have not been adequate. Spills which create airborne dusts do occur in spite of the best care. The problem has finally been solved by replacing the workers with automatic equipment. Electric vibrating hammers have now been installed on most of the cottrell units.

By-Products Metals: The control of dusts and gases in the refining and packaging of by-product elements, such as selenium, tellurium, and cadmium, has been accomplished by use of local exhaust ventilation almost exclusively.

Fig. 8—Workmen extracting flue dust with use of telescopic tube device designed for control of dusts by wetting and enclosure.

The hygiene program and some of the work that has been done to improve working conditions in the American Smelting and Refining Co. have been reviewed briefly. In presenting this information there is no wish to convey the impression all objectives have been reached. There are problems yet to solve, and changes in operations and new processes continually arise which require study and control. In one smelter recently the minutest details of control in a new process were worked out before the plant was built in order that no chances would be taken. Top management and operating staffs displayed keen interest and cooperated to the fullest extent. The same interest and cooperation from managements of all plants have existed in all other phases of the industrial hygiene program and are largely responsible for what measure of success has been achieved.

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[2] B. R. Small, with supplement by C. A. Stevenson: Air Conditioned Crane Cabs. Engineering Series publication by Industrial Hygiene Foundation of America. Mellon Institute, Pittsburgh, Pa. 1946.

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Solution Loss and Reducing Power Of Blast Furnace Gas

by T. L. Joseph

A study is made of the amount of solution loss necessary to maintain the reducing power of the gas stream in the blast furnace. Curves are presented to show the effect of solution loss, moisture in the blast, and carbon dioxide from the flux on the nitrogen in the top gas.

THE blast furnace process is based upon the counter flow of gases and solids. As CO, N_2 and H_2 flow upward from the combustion zones, oxygen is acquired from the descending charge. In the reduction of iron ore, a portion of CO is converted to CO_2 and similarly a portion of H_2 is converted to water vapor. The inert N_2 from the air used in combustion, passes through the furnace with little change. Its concentration is, however, decreased by reactions such as direct reduction and solution loss which increase the volume of CO in the gas stream. Similarly the evolution of CO_2 from the limestone also dilutes the nitrogen.

The purpose of this paper is to illustrate an idealized and simplified method of studying furnace processes by following changes in the gas phase between the tuyeres and the stock line. A more specific objective is to evaluate the effect of solution loss upon the CO/CO_2 ratio in that region of the furnace in which FeO is reduced to metallic iron. This last stage of reduction requires relatively high CO/CO_2 ratios to exceed the equilibrium requirements. Solution loss or the reaction of CO_2 with C to produce CO has a pronounced effect upon the ratio of the carbon gases and is necessary to maintain the reducing power of the gas stream if the consumption of coke is low. It will be explained later that indirect reduction followed by solution loss is stoichiometrically equivalent to direct reduction.

Calculations will be made to show how the composition of the gas in the region of the mantle varies with coke consumption and with different amounts of solution loss. Such calculations show the conditions under which gasification of C with oxygen in the charge is needed to maintain the reducing power of the gas. Equilibrium conditions for FeO and the carbon gases will be used to establish a minimum CO/CO_2 ratio below which reduction will not proceed. The manner in which carbon is gasified in the furnace, at the tuyeres with oxygen in the air or above the tuyeres with oxygen from the charge, will be a basic feature of all calculations. It is hoped that greater interest in the use of top gas as a means of following furnace reactions will be aroused by the calculations and generalized curves which are presented.

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Bosh Gas Equations

Subject to some alteration by the amount of moisture in the blast and by direct reduction, the gas leaving the combustion zones of a blast furnace has a definite composition. Because a relatively small amount of oxygen is acquired from the charge in the bosh and in the crucible, the products of combustion undergo little change until they enter the shaft. Bosh gas is, therefore, essentially the products of combustion of carbon in a deep fuel bed with air. The relative weights and volumes of reacting materials are expressed by the equation:

$$\underset{\text{Air}}{2C + O_2 + 3.76N_2} = \underset{\text{Bosh Gas}}{2CO + 3.76N_2} \qquad [1]$$

$$\left(\text{air} = \frac{79\%\ N_2}{21\%\ O_2} = 3.76\right)$$

Starting with a known mass of C consumed largely by air, Eq 1, but partly by water vapor, Eq 2, the volume and

$$C + H_2O = CO + H_2 \qquad [2]$$

composition of the bosh gas can be calculated and subsequent changes followed as reactions take place at various elevations in the furnace. As shown in

Fig. 1, bosh gas is converted to intermediate gas which in turn is converted to top gas.

Changes in Composition of Gas Stream

The reactions that produce the major changes in the gas stream are given in Fig. 2 in terms of pound mols,* a convenient unit of volume as well as of mass. Except for the amount of carbon burned at

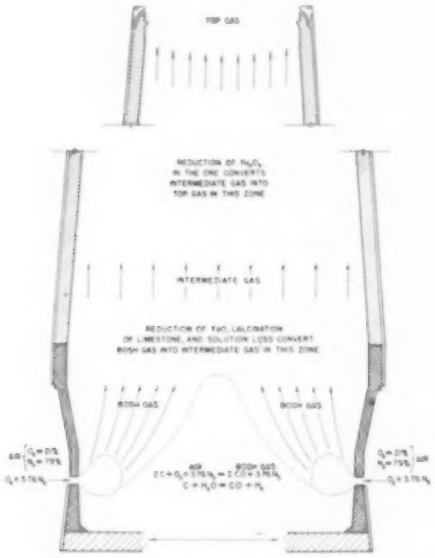
TOP GAS
REDUCTION OF Fe_2O_3 IN THE ORE CONVERTS INTERMEDIATE GAS INTO TOP GAS IN THIS ZONE
INTERMEDIATE GAS
REDUCTION OF FeO, CALCINATION OF LIMESTONE, AND SOLUTION LOSS CONVERT BOSH GAS INTO INTERMEDIATE GAS IN THIS ZONE
BOSH GAS
BOSH GAS
AIR
BOSH GAS
$C + O_2 = CO_2$
$C + H_2O = CO + H_2$

Fig. 1—Major changes in composition of blast furnace gas.

the tuyeres the items reported in Table I are available from routine operating data. A method of calculating the pounds of carbon consumed at the tuyeres has been published.[1]

In setting up the equations and the material balance presented in Fig. 2, it has been assumed that 1086 lb or 90.5 mols of C are gasified at the tuyeres with the moist blast and that 208 lb or 17.33 mols are gasified above the tuyeres with oxygen from the charge. Once the carbon consumed at the tuyeres is fixed, the volume of air required is fixed. In this case, 209.44 lb mols or 79,500 ft³ of dry air is needed to consume 88 mols of carbon. (379.4 ft³/lb mol × 209.44 lb mols = 79,500 ft³).

With a moisture content of about 4 grains per ft³, this volume of air will contain 2.5 mols of water which will consume 2.5 mols, or 30 lb, of carbon.

Subject to slight modification by the amount of moisture in the blast and by the CO produced by direct reduction or solution loss in the crucible, the composition of the gas leaving the combustion zones will conform rather closely to that given under bosh gas in Fig. 2. The total volume of gas issuing from the combustion zones per ton of iron produced will vary with the carbon gasified at the tuyeres. In this case 98,000 ft³ of gas containing 35 pct CO, 64 pct N_2, and 1 pct H_2 are formed per ton of iron. At the inward extremities of the combustion zones and particularly in the central idle core where gas flow is restricted, the CO may be higher and the N_2 lower than given in Fig. 2.

A relatively small amount of CO, 2.5 mols or 950 ft³, is formed during the reduction of MnO, SiO_2, and P_2O_5 in the bosh and in the crucible. There is no way of knowing what proportion of the metalloids is reduced in the hearth. For simplicity, it is assumed that most of the CO from direct reduction enters the gas stream in the bosh.

Change from Bosh Gas to Intermediate Gas

The term bosh gas refers to the gas formed in the high-temperature combustion zones adjacent to the tuyeres. Because a comparatively small amount of oxygen is removed from the charge in the bosh, the gas stream undergoes little change in this part of the furnace. Near the top of the bosh and in the lower part of the shaft a number of reactions take place because all of them proceed at temperatures ranging from 1100°C down to 800°C. Ferrous oxide is reduced, the limestone calcines, and CO_2, either from calcination or from indirect reduction, reacts with carbon according to the solution loss reaction. These reactions representing the acquisition of oxygen from the charge as CO and CO_2 are summarized in Fig. 2.

As indicated in Table I, a net ton of pig iron will contain about 1840 lb of Fe equivalent to 2374 lb or 33.05 mols of FeO. It is arbitrarily assumed that one half the H_2 from the combustion zone reacts with 1.25 mols of FeO, and that the remaining 31.80 mols of FeO are reduced with CO. The amount of H_2 involved in reduction is normally relatively small but additions of steam to the blast could lead to a substantial reduction in the amount of CO_2 formed and in the ratio of the carbon gases.

By making appropriate adjustments for the carbon gasified in the reduction of metalloids, and for the carbon dissolved in the iron, it is possible to determine the weight of carbon gasified above the

Table I. Typical Data for Calculating Changes in Composition of Blast Furnace Gas

Carbon Balance	Lb	Lb Mols
Coke per ton of pig	1,560	
Carbon per ton of pig	1,404	117.0
Carbon burned with O_2 at tuyeres	1,056	88.0
Carbon consumed with H_2O at tuyeres	30	2.5
Total carbon at tuyeres	1,086	90.5
Carbon dissolved in pig	80	6.66
Carbon used in reducing P_2O_5, and MnO and SiO_2	30	2.50
Carbon from coke gasified in furnace	1,324	110.33
Carbon from coke gasified at tuyeres	1,086	90.50
Carbon from coke gasified above tuyeres	238	19.83
Carbon gasified in direct reduction	30	2.50
Carbon gasified in solution loss	208	17.33
Carbon dioxide from limestone	352	8.0

Lb of Fe, FeO, and Fe_2O_3

2,000 lb × 0.92	=	1,840 lb Fe per ton pig
1,840 × 1.29	=	2,374 lb FeO per ton pig
2,374 / 71.84	=	33.05 lb mols of FeO
1,840 × 1.43	=	2,631 lb Fe_2O_3 per ton pig
2,631 / 159.68	=	16.53 lb mols Fe_2O_3

* A pound mol or molecular weight of any gas expressed in pounds occupies 359 ft³ at 32°F and 29.92 in. of Hg or 379.4 ft³ at 60°F and 14.7 psi.

tuyeres. The exact mechanism of gasification is not known, but it seems more logical to assume that gas-solid reactions are more likely to occur than those between two solids such as FeO and carbon. The effect of variations in the amount of C gasified above the tuyeres on the CO/CO_2 ratio will be considered later. For the immediate purpose of illustrating the method, it has been assumed that 208 lb or 17.33 mols of C reacts with CO_2, a portion of which may be produced by the calcination of 8 mols or 800 lb of calcium carbonate.

By combining the results of the CO and CO_2 balances of Fig. 2, it is noted that the conversion of bosh gas to intermediate gas adds 5.36 mols of CO and 22.47 mols of CO_2 to the bosh gas. This increase of 27.83 mols, equivalent to 10,610 ft³, has diluted the N_2 from 64.0 to 58.0 pct. The percentage of CO in the intermediate gas is almost as high as in the bosh gas; 33.4 compared with 35. Due largely to the solution loss reaction, the gas contains but 7.8 pct CO_2 giving a CO/CO_2 ratio of 4.3. Thus if certain assumptions are made, some interesting observations may be made on the changes in the gas stream.

Conversion of Intermediate Gas to Top Gas

The early step of reduction or the conversion of Fe_2O_3 through Fe_3O_4 to FeO takes place at much lower temperatures than the last step of reduction, i.e., the conversion of FeO to metallic iron. It seems permissible, therefore, to think of another major change in composition of the gas stream brought about by the reduction of Fe_2O_3 to FeO in the upper part of the shaft by the reaction

$$16.53Fe_2O_3 + 16.53CO = 33.06FeO + 16.53CO_2 \quad [3]$$

The effect of this reaction, which involves no increase in volume but merely a conversion of CO to CO_2, is readily determined as shown in Fig. 2.

The H_2 in the calculated top gas of Fig. 2 is low because the reaction

$$H_2O + CO = CO_2 + H_2 \quad [4]$$

has not been considered. Some moisture from the charge is decomposed in the upper part of the furnace, but the reactions involved have not been established. Reaction 4 would reduce the CO/CO_2 ratio of 2.03 given for the top gas in Fig. 2 to 1.75 if 4 mols of hydrogen were so formed. The decomposition of water vapor by metallic iron would not alter this ratio. Until more information is available, the ratio given in Fig. 2 is tentative.

Knowing the blast moisture and the carbon used in solution loss and the composition of the top gas, one could determine the amount of H_2 formed in the upper part of the furnace. A comparison of actual CO/CO_2 ratios with calculated ratios based upon the formation of this H_2 by reaction 4 would shed some light on the mechanism of water decomposition in the upper shaft. Moisture added to the skip may react differently from water combined in the ore because the latter would come off at somewhat higher temperature. It is unlikely that moisture in the charge would persist low enough in the furnace in any case to change the intermediate gas.

Solution Loss and Direct Reduction

Although the writer prefers to think of the gasification of C above the tuyeres as a gas-solid reaction, many prefer to associate this phenomena with the direct reduction of FeO by the reaction

$$FeO + C = Fe + CO \quad [5]$$

A few calculations will show that the final results are stoichiometrically the same whether we consider the carbon is gasified by reacting with CO_2 gas or with solid FeO. Beginning with the same volume and composition of bosh gas as given in Fig. 2 and

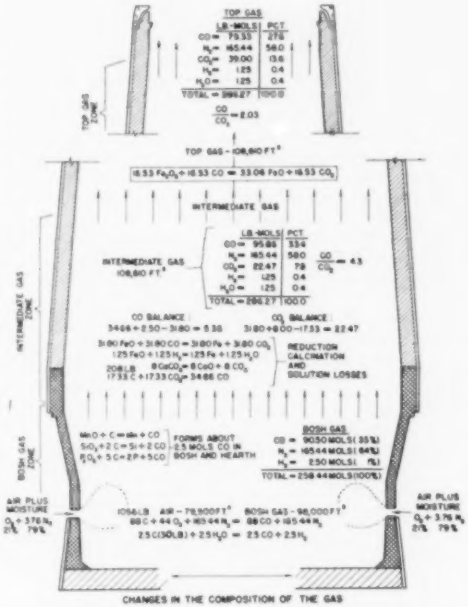

Fig. 2—Detailed changes in composition of blast furnace gas.

considering the effect of gasifying 208 lb of C in direct reduction rather than with solution loss, the reactions for the conversion of bosh gas to intermediate gas are as follows:

$$17.33FeO + 17.33C = 17.33Fe + 17.33CO \quad [6]$$

$$1.25FeO + 1.25H_2 = 1.25Fe + 1.25H_2O \quad [7]$$

$$14.47FeO + 14.47CO = 14.47Fe + 14.47CO_2 \quad [8]$$

The net result of these three reactions is a gain of 2.86 mols of CO and a gain of 14.47 mols of CO_2. If 2.5 mols of CO from direct reduction is added, as was done in the CO balance of Fig. 2, the same total increase of 5.36 mols of CO is obtained. For CO_2 the gain is also the same as in Fig. 2, if 8 mols from the limestone is added. According to this mechanism, the conclusion would be that 17.33 mols of FeO out of 33.05, or about 56 pct of the iron, is reduced directly with solid C and 44 pct with H_2 and CO. To the writer the implications of such a division of reduction is not as meaningful as the statement that 208 lb of C are gasified with CO_2 with a loss of 5,830 Btu per lb of C. However, the method described can be used to study the process regardless of the preferred mechanism for reduction.

The gasification of carbon by oxygen from the charge is presumably more detrimental if it occurs at lower levels in the furnace. Unfortunately top-gas analyses or the calculations under discussion do not show where solution loss or direct reduction occur. They merely show the amount of C involved, the thermal effect and the effect on the volume and composition of the gas stream. Obviously carbon deposition cannot be isolated by the use of top-gas analyses.

Solution Loss and Reducing Power of Gas Stream

The amount of C consumed at the tuyeres to satisfy the heat requirements, the amount of CO_2 from the limestone, and the moisture in the blast all have a bearing upon the CO/CO_2 ratio in the region of the mantle. Solution loss has a very pronounced effect upon this ratio because it involves the conversion of 1 mol of CO_2 into 2 mols of CO. By calculations similar to those in Fig. 2 the effect of each of these factors can be studied.

Intermediate gas compositions were calculated for amounts of solution loss ranging from 0 to 300 lb and for amounts of carbon consumed at the tuyeres

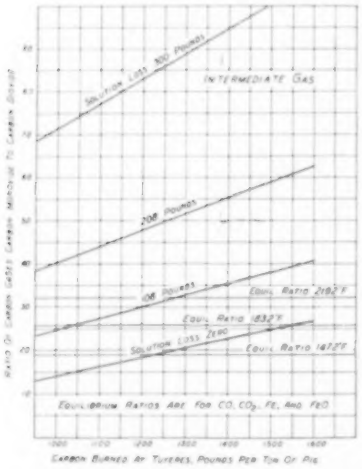
INTERMEDIATE GAS
208 POUNDS
108 POUNDS
EQUIL. RATIO 2192°F
EQUIL. RATIO 1832°F
SOLUTION LOSS ZERO
EQUIL. RATIO 1472°F
EQUILIBRIUM RATIOS ARE FOR CO, CO2, FE, AND FEO
CARBON BURNED AT TUYERES, POUNDS PER TON OF PIG

Fig. 3—Equilibrium and calculated carbon gas ratios in the intermediate gas.

ranging from 1000 to 1600 lb. This range of carbon burned at the tuyeres would be equivalent to from 1400 to 2300 lb of coke charged per ton of iron. In making these calculations the volume of CO_2 from the flux and the effect of moisture in the blast were held constant. The results of these calculations showing the effect of carbon burned at the tuyeres and solution loss on the CO/CO_2 ratio in the intermediate gas are shown as generalized curves in Fig. 3. Equilibrium ratios of the carbon gases in contact with FeO at temperatures of 1472°, 1832°, and 2192°F have also been plotted in this figure to show the conditions under which these ratios are exceeded and reduction can occur. Equilibrium ratios for other temperatures, taken from Austin and Day,[5] are given in Table II.

It seems evident from Fig. 3 that when the solution loss exceeds 208 lb, the intermediate gas will be reducing towards ferrous oxide. Consider, for example, the case when 1200 lb of C is consumed at the tuyeres. The consumption of 208 lb of C by solution loss, 30 lb by reduction of metalloids, and 80 lb by solution in the iron, would mean that 1518 lb of C or about 1700 lb of coke are charged per ton

Table II. Equilibrium Ratios of Carbon Gases in Contact with FeO

Temperature			Temperature		
Deg F	Deg C	Ratio CO/CO_2	Deg F	Deg C	Ratio CO/CO_2
752	400	0.74	1,652	900	2.24
932	500	0.96	1,832	1,000	2.57
1,112	600	1.17	2,012	1,100	2.88
1,292	700	1.53	2,192	1,200	3.21
1,472	800	1.90	2,372	1,300	3.47

of iron. Under these conditions, the CO/CO_2 ratio of the intermediate gas is equal to 4.75 compared with an equilibrium ratio of 1.9 at 1472°F (800°C).

For an overall appraisal of the situation it appears that a CO/CO_2 ratio of 3 or higher should be maintained. Such a ratio would require that a minimum of 1200 lb of C be burned at the tuyeres if 108 lb of C be consumed in solution loss, see Fig. 3. Gruner's ideal furnace would require the consumption of over 1700 lb of C at the tuyeres, equivalent to over 2000 lb of coke charged, to obtain a CO/CO_2 ratio of 3 in the intermediate gas. Thus it may be seen that only when large amounts of fuel are needed to satisfy fuel requirements can furnaces operate without solution loss. It appears that a solution loss of some 200 lb, which is typical of Lake ore practice, may be reduced to about 100 lb without exhausting the reducing power of the intermediate gas. The combustion of an additional 100 lb of C at the tuyeres rather than the gasification of an equal amount above the tuyeres would increase the heat made available to the process by about 1,000,000 Btu. The fact that about 200 lb of C is consumed above the tuyeres merely means that operations are not on properly sized and easily reduced ore burdens.

Assuming that 108 lb, or 9 mols, of C must be gasified above the tuyeres to maintain the reducing power of the gas, it follows that 9 mols of FeO must be reduced directly with solid carbon. This would correspond with about 27 pct of the 33.05 mols of FeO needed to produce the metallic iron in a net ton of pig iron. For those who prefer to think in terms of the solid carbon or direct reduction reaction, it appears, therefore, that some 25 pct of direct reduction is necessary in typical Lake ore practice to maintain the reducing power of the bosh gas.

Effect of Countercurrent Flow

Under the conditions of countercurrent flow of the blast furnace, the descending ore burden comes in contact with ascending gas progressively higher in CO and progressively hotter. This offers distinct advantages because the charge richest in FeO comes in contact with gas at the lowest temperature and with the lowest CO/CO_2 ratio. On the other hand, the charge containing very little FeO in the final

stages of reduction comes in contact with bosh gas containing little, if any, CO_2.

Calcination of the limestone and the reaction of CO_2 with C begin very slowly at about 1400° and increase rapidly with temperature above 1800°F. In preparing Fig. 4 it has been assumed for the sake of simplicity that reduction, calcination, and solution loss take place in 10 equal steps as the charge moves through a temperature range of 1400° to 2400°F. As indicated, bosh gas containing no CO_2

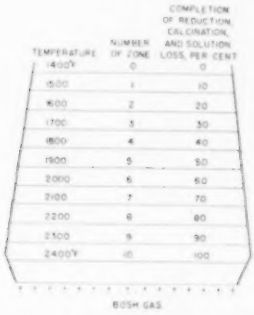

Fig. 4—Steps in the conversion of bosh gas to intermediate gas.

enters zone 10, in which the last 10 pct of FeO is reduced to metallic iron. Moving through the successive zones, the gas stream acquires oxygen from the charge and finally emerges as intermediate gas having acquired the oxygen associated with the first stages of reduction of FeO and the first stages of calcination. As shown in Fig. 3, this gas has a definite composition under fixed conditions of fuel consumption, blast moisture, limestone requirements, and solution loss.

Calculated and Equilibrium Ratios of Carbon Gases

As shown in Table II, higher CO/CO_2 ratios must be maintained to facilitate reduction at higher temperatures. For example, the equilibrium ratio increases from 1.9 at 1400°F to 3.5 at 2400°F. Fortunately, the gas is very rich in CO at the highest temperature, as indicated by the calculated CO/CO_2 ratios given in Fig. 5. It appears that the closest approach to equilibrium occurs in the early stages of FeO reduction and in the early stages of calcination. In this cooler part of the shaft the equilibrium ratios are somewhat less than 2 whereas the calculated ratio at the lowest temperature indicates a value of 3 for the CO/CO_2 ratio. When 1200 lb of C are burned at the tuyeres, a solution loss of 108 lb will, it appears, maintain reducing conditions in the gas stream. If conditions of higher fuel consumption or higher solution loss were assumed, a series of generalized curves similar in shape to the upper one in Fig. 5, but at higher positions, would be obtained.

Nitrogen in Top Gas as Key to Solution Loss

In as much as the N_2 of the blast is relatively inert and passes through the furnace without reaction, it can be very useful as a measure of solution loss or direct reduction.

Brief reference to Fig. 2 will show how and to what extent a change in solution loss alters the volume of the gas and in turn the degree of the dilution of nitrogen. Each pound mol of C that reacts with CO_2

$$C + CO_2 = 2CO \qquad [9]$$

increases the volume of the gas stream by 1 mol. A mol of CO_2 is consumed, but 2 mols of CO are formed by reaction 9.

If in place of the 208 lb of solution loss, considered in Fig. 2, only 100 lb of C is gasified, the gas volume will be reduced by 9 mols. That is the 286.27 mols of intermediate gas and top gas will be reduced to 277.27 mols. The constant volume of 165.44 mols of N_2 is now equal to 59.7 pct of the total volume; an increase of 1.7 pct over the value of 58.0 pct reported in Fig. 2. Thus, a decrease of 108 lb in solution loss results in an increase of 1.7 pct in the N_2 content of the intermediate and in the top gas. For a fixed coke rate high N_2 means low solution loss.

In a given practice the CO_2 from the stone and the moisture in the blast will remain fairly constant but their effects on N_2 dilution are appreciable. For example, an increase of 200 lb of $CaCO_3$ or 2 mols would increase the gas volume to 288.27 mols, thus reducing the N_2 from 58.0 to about 57.5 pct. Similarly, each mol of C consumed in the water gas reaction

$$H_2O + C = CO + H_2 \qquad [10]$$

adds 2 mols of gas without contributing any nitrogen. Thus one additional mol of C consumed at the tuyeres with moisture in the blast and 2 additional mols of $CaCO_3$ in the limestone dilute the N_2 to about

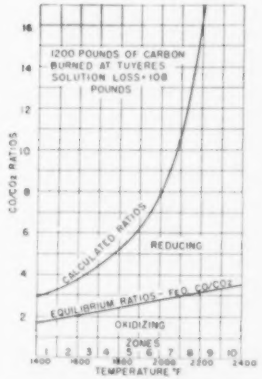

Fig. 5 — Calculated and equilibrium carbon gas ratios at various temperatures.

the same degree. The specific affects of solution loss, CO_2 from the stone and moisture in the blast will be considered in greater detail later.

Fuel consumption also has a bearing upon the dilution of nitrogen. High fuel requirements normally mean more air and more N_2 per ton of pig. The combined action of solution loss, calcination, and direct reduction in diluting the N_2 will generally be less when the fuel consumption is high. In other words, a high N_2 content of the top gas is normally

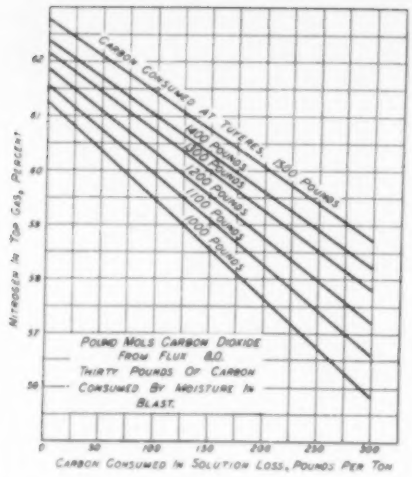
Carbon Consumed At Tuyeres, 1500 Pounds
1400 Pounds
1300 Pounds
1200 Pounds
1100 Pounds
1000 Pounds
Pound Mols Carbon Dioxide From Flux 8.0.
Thirty Pounds Of Carbon Consumed By Moisture In Blast.
Nitrogen In Top Gas, Percent
Carbon Consumed In Solution Loss, Pounds Per Ton

Fig. 6—Fuel consumption solution loss and the nitrogen content of top gas.

associated with high fuel consumption. Sufficient progress has been made in equipment to get continuous records of top-gas composition to warrant further study of the significance of such data as an index of furnace reactions.

A generalized picture of the effect of solution loss upon the N_2 content of the top gas is given in Fig. 6. Following the methods previously described, the composition of the top gas was calculated for zero up to 300 lb of solution loss and for 1000 to 1500 lb of C at the tuyeres per ton of pig iron. If the fuel consumption is high, the nitrogen in the blast required to consume this large amount of carbon suffers less dilution by CO_2 from the limestone, by the solution loss reaction and by the direct reduction of metalloids. With a constant solution loss of 200 lb the top gas will, according to Fig. 6, contain about 60 and 57.6 pct N, respectively, when 1500 and 1000 lb of C are burned at the tuyeres.

When fuel requirements are fairly fixed as indicated by each of the six curves, the N_2 in the top gas becomes an index of solution loss. For example if the heat requirements are such as to demand about 1100 lb of C at the tuyeres, the N_2 in the top gas will drop from 59.9 to 58.2 pct if the solution loss increases from 100 to 200 lb per ton of iron. Such changes in N_2 are readily detected so that with properly prepared curves to compensate for moisture in the blast and CO_2 from the stone, top-gas analyses afford a direct means of following solution loss.

In order to observe the dilution of N_2 in the top gas by blast moisture, calculations were made for three levels of moisture in the blast: dry blast, 3.82 and 7.64 grains-ft^3. With these respective amounts of moisture in the blast, zero, 30 and 60 lb of C would be consumed per ton of iron. This assumes a constant volume of 82,500 ft^3 of dry air, capable of burning 1100 lb of C at the tuyeres per ton of iron

$$\left(\frac{4.76 \times 379.4}{24} = 75 \text{ ft}^3 \text{ air per lb of C}\right).$$

The action of moisture in the blast as a N_2 diluent is summarized in Fig. 7 for a wide range of solution loss. An increase of 3.82 grains of blast moisture lowers the N_2 in the top gas by about 1 pct. It does so of course because this amount of moisture will consume 2.5 mols of C and produce 5 mols or 1897 cu ft of H_2 plus CO.

Except for the endothermic effect of the water gas reaction it represents a form of oxygen enrichment. A pound mol of water vapor will gasify a pound mol of C whereas it requires 2.38 mols of air per mol of C, see Fig. 1. Thus the combustion potential of 1 ft^3 of water vapor is equivalent to 2.38 ft^3 of dry air. On the gas produced side, it is of interest to note that 2 mols of H_2 plus CO are produced per mol of C consumed with H_2O whereas 2.88 mols of CO and N_2 are produced per mol of C gasified with dry air. In other words, high moisture favors a more rapid rate of driving because of the greater combustion potential of moisture and also because less gas is produced per pound of C gasified.

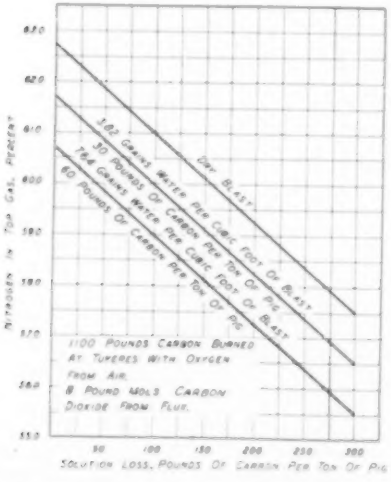
Dry Blast.
3.82 Grains Water Per Cubic Foot Of Blast.
30 Pounds Of Carbon Per Ton Of Pig.
7.64 Grains Water Per Cubic Foot Of Blast.
60 Pounds Of Carbon Per Ton Of Pig.
1100 Pounds Carbon Burned At Tuyeres With Oxygen From Air.
8 Pound Mols Carbon Dioxide From Flux.
Nitrogen In Top Gas, Percent
Solution Loss, Pounds Of Carbon Per Ton Of Pig

Fig. 7—Moisture in the blast and nitrogen in the top gas.

Effect of Limestone on Nitrogen in Top Gas

The effect of CO_2 from the stone as shown in Fig. 8 can be seen very readily if it is remembered that each additional 100 lb of flux represents about 100 lb, or 1 mol, of $CaCO_3$ equivalent to 1 mol of CO_2. An increase from 800 to 1100 lb of flux means, therefore, an addition of about 3 mols of CO_2 or roughly 1.0 pct of the 286.27 mols shown in Fig. 2. Since the gas contains about 58.0 pct N_2 such a percentage reduction would be a reduction of about 0.6 pct N_2. Such a reduction in N_2 can be observed for each of the three levels of carbon consumption in Fig. 8. In general, the effects of changes in the amount of flux used will be masked by the effect of solution loss or blast moisture. However, adjustments must be made for variations in the flux to isolate the effect of solution loss.

Since the details of calculations for dealing with furnace problems in pound mols have been given in the hope that it may be of value in studying the smelting process, it may be permissible to show how the method assists in following other changes as well as changes in solution loss. Suppose, for example,

that 900 lb of high-combined moisture material were substituted for 900 of a low-combined moisture material such as sinter. An increase of 10 pct in combined moisture would represent 90 lb, or 5 mols, of water vapor. This would be equivalent to an increase of about 1.75 pct in the volume of the gas liberated in the upper part of the shaft and may necessitate a slower rate of operation in the case of a furnace already blown near the maximum rate.

Solution Loss and Volume of Gas Generated

Since 1938, the demand for steel and pig iron has been conducive to operation of blast furnaces at maximum rates consistent with efficiency and the production of flue dust. Under these conditions, the linear velocity of the gas through the stock imposes the final limitation on the amount of wind that can be blown in a given furnace. Although solution loss or the oxidation of carbon above the tuyeres by oxygen in the charge reduces the volume of gas generated per pound of carbon gasified in the furnace as a whole, the use of high-top pressure, described in a number of reports,[2,3] is a more effective

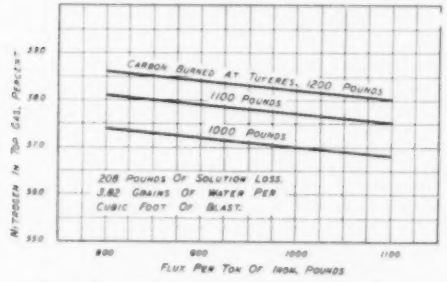

Fig. 8—Flux requirements and nitrogen in the top gas.

way of reducing linear gas velocities without disturbing the thermal balance of the operation.

In the calculations of Fig. 2, 208 lb of C are consumed above the tuyeres and 1056 at the tuyeres with dry air. It may be assumed that a more easily reduced burden, better gas distribution, and smaller limestone reduce solution loss by 108 lb, or 9 mols, of C. Under these conditions the 9 additional mols of C to be consumed at the tuyeres per ton of pig iron would require 21.42 additional mols of air and 25.92 additional mols of bosh gas would be produced per ton of pig iron.

$$\left(9 \times \frac{4.76}{2} = 21.42;\ 9 \times \frac{5.76}{2} = 25.92\right)$$

This may be compared with the combustion reaction, Fig. 1. This increase in the volume of bosh gas would be partly offset by a reduction of 9 mols in the gas produced by solution loss.

The net effect of more bosh gas and a reduction in the volume of CO from solution loss would be the addition of 16.92 mols of intermediate gas per ton of pig. On the basis of 286.27 mols of intermediate gas, this is equivalent to an increase of 5.9 pct in the volume of the gas per ton of iron.

Such an increase in the gas to be forced through the charge may, in the case of a furnace operating near critical gas velocities, lead to channelling, an increase in dust production, and less favorable heat transfer. It is conceivable, therefore, that a decrease in solution loss may result in a temporary loss of tonnage. Actually, a decrease of 108 lb of solution loss would increase the heat available to the process by about 1,000,000 Btu. It seems more likely that such an increase in available heat would result in some increase in hearth temperature which would in turn permit a reduction in fuel, in air, and in the gas produced to the end that there would be a reduction in fuel required but not in tonnage. A high-solution loss of carbon does not appear to be a proper way to reduce gas velocities in the furnace shaft. Size preparation of the ore or high-top pressures would appear to be more promising methods of reducing the linear velocity of the gas through the stock.

Summary and Conclusions

Further study of the gas phase of the blast furnace process offers a means of learning more about the process. Simple calculations based upon the use of the pound mol to make a material balance indicate that the consumption of about 100 lb of C in solution loss or by direct reduction of FeO will maintain a reducing gas in the region of the mantle in typical Lake ore practice. Few data are available but it appears that about 200 lb of C normally is consumed above the tuyeres. More reducible burdens and burdens better prepared physically will be necessary to make an additional million Btu available to the process by a reduction of 100 lb in the C gasified above the tuyeres.

An increase in solution loss temporarily increases the rate of furnace driving for a constant rate of blowing merely because more carbon is gasified with oxygen from the charge. However, since the heat available is reduced, more fuel eventually must be used so that in the end solution loss in excess of about 100 lb means a loss of both tonnage and efficiency. With better prepared burdens physically or with higher top pressures, the additional gas produced by burning more carbon at the tuyeres should not present a problem.

The generalized curves illustrate what can be done with calculations similar to those outlined in the paper. They are not intended for general use but as a guide for similar curves made to fit a particular practice. It is to be hoped that continuous top-gas analysis will be used in interpreting what is going on in the furnace to the end that more will be learned about the basic features of the smelting process. All will agree that a better understanding of the process is needed to appraise the value of new raw materials as well as innovations in practice such as high-top pressures, beneficiated ore burdens, and oxygen enriched blast.

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Metallographic Study of the Martensite Transformation in Lithium

by J. S. Bowles

THE martensite transformation in lithium, discovered by Barrett,[1] has been studied extensively by X-ray techniques by Barrett and Trautz,[2] and Barrett and Clifton.[3] The present paper reports the results of an investigation into the metallographic characteristics of lithium martensite. Such an investigation has not been carried out before.

The spontaneous transformation in lithium consists of a change from a body-centered cubic to a close-packed hexagonal structure with the hexagonal layers in imperfect stacking sequence.[4] As far as is known at present, this transformation can be regarded as being crystallographically equivalent to the body-centered cubic to close-packed hexagonal transformation that occurs in zirconium,[5] although stacking errors have not been reported in zirconium.

From a study of the orientation relationships in zirconium, Burgers[6] has proposed that the martensite transformation, b.c.c. to c.p.h., occurs by a heterogeneous shear on the system (112) [11$\bar{1}$]. The crystallographic principle underlying this proposal is that the configuration of atoms in the (112) plane of a b.c.c. structure is exactly the same as that in the (10$\bar{1}$0) plane of a close-packed hexagonal structure based on the same atomic radius. The pattern in both these planes is a rectangle $d \times \frac{2\sqrt{2}}{\sqrt{3}} d$ where d is the atomic diameter. Thus a close-packed hexagonal structure can be built up from a body-centered cubic structure by displacing the (112) planes relative to each other.* This mechanism leads to orientations that can be described by the relations:

$$(110)_{b.c.c.} \;//\; (0001)_{c.p.h.}; \; [\bar{1}11]_{b.c.c.} \;//\; [11\bar{2}0]_{c.p.h.}$$

Observations confirm these relations. In zirconium, Burgers' measurements indicated an angle of 0° to 2° between the close-packed directions, while Barrett's measurements on lithium indicated an angle of 3°.

According to the Burgers' mechanism, the martensite habit plane for this transformation would be expected to be the $(112)_{b.c.c.}$ plane, for this plane would not be distorted by the transformation. One of the purposes of this investigation was to find out whether the observed lithium habit plane agrees with this prediction of the Burgers' mechanism.

Experimental Procedure

Materials: The lithium was from the same purified ingot used by Barrett and Trautz.[7] The Bridgman technique was used to produce single crystals. To maintain a temperature gradient in the melt, during the production of these crystals, it was necessary to use a steel mould with a wall thickness of only 0.015 in.

Metallographic Techniques: Lithium specimens could be given an excellent metallographic polish by swabbing them gently with cold methyl or ethyl alcohol.† The best results were obtained with methyl alcohol saturated with the reaction product, lithium alcoholate. With higher alcohols the reaction became progressively slower and the attack became an etch pit attack rather than a polish attack. Butyl and amyl alcohols were used for macroetching.

After polishing, it was necessary to remove all traces of alcohol from the specimens; otherwise, on subsequent quenching in liquid nitrogen, the alcohol froze to a glassy film. The alcohol was removed with dry benzene. The benzene in turn had to be removed before quenching, but since it does not react with lithium it could be allowed to evaporate. The specimens could then be quickly quenched before they began to tarnish. This operation could be carried out in air on all but excessively humid days when it was advisable to use an atmosphere of dry nitrogen or argon. For examinations at room temperature, the specimens could be transferred directly from the benzene bath into a bath of mineral oil. In mineral oil the specimens oxidized slowly by the diffusion of oxygen through the oil but the structure remained visible for about an hour.

Lithium Martensite: Specimens prepared in the manner described above transformed spontaneously to martensite with an audible click when quenched into liquid nitrogen; i.e., M_s was above the boiling point of nitrogen (77°K). The disparity between this result and the M_s temperature of 71°K, found by Barrett and Trautz, is probably to be attributed to the large grain size and freedom from mechanical deformation of the specimens used in the present work.

The relief effects produced by the transformation did not disappear when specimens were quenched from liquid nitrogen into mineral oil at room temperature. This permitted the microstructures to be studied at room temperature where, of course, the martensitic phase was no longer present. Typical micrographs of lithium "martensite" made at room temperature are reproduced in figs. 1, 2, and 3. As anticipated by Barrett and Trautz, the microstruc-

* It should be noted that the array on the $(110)_{b.c.c.}$ plane cannot be converted into an exact hexagonal array by the simple shear proposed by Burgers, since the spacings of the $(112)_{b.c.c.}$ and $(10\bar{1}0)_{c.p.h.}$ planes are not exactly equal. A contraction would have to be superimposed on the proposed shear.

† Sodium can also be polished metallographically in this way, using propyl alcohol instead of methyl alcohol.

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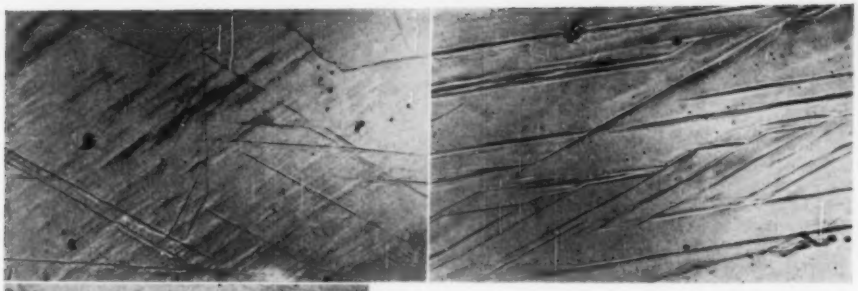

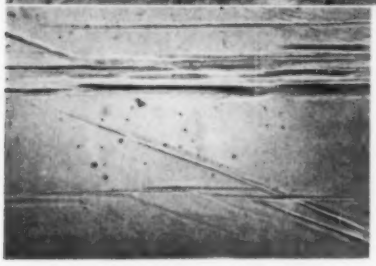

Fig. 1 (upper left)—Lithium martensite relief effects photographed at room temperature. X100.

Fig. 2 (upper right)—Lithium martensite relief effects photographed at room temperature. X150.

Fig. 3 (lower left)—Lithium martensite relief effects photographed at room temperature. X200.

tural characteristics of lithium martensite were essentially similar to those of other martensitic phases. The relief effects produced by the transformation consisted essentially of a simple tilting of the surface about its intersection with the habit plane. This type of relief appeared to be typical of martensite transformations. The lithium martensite plates also frequently showed a set of transverse markings. As in other systems, the transformation at M_s appeared to be a highly cooperative affair, for a whole network of plates suddenly appeared. Apparently many plates, both in the same crystal and in neighboring crystals, were triggered off by the formation of the first plate. The zig-zag linkage, which is so predominant a feature of other martensitic structures, also occured very frequently.

When a specimen was covered with a frozen film of alcohol, martensite relief effects were not produced on the surface on quenching into liquid nitrogen, i.e., these films appeared to suppress the transformation. These films were quite transparent, and although they had the form of a cracked mosaic, the microstructure of the underlying lithium could be seen quite clearly. Many specimens coated with alcohol films were cooled to the melting point of nitrogen (63°K), i.e., more than 14° below M_s, and no relief effects were ever observed. Films of frozen propane caused the same behavior. X-ray diffraction experiments were carried out at liquid nitrogen temperature to see whether the films completely inhibited transformation. In general diffraction lines of the martensite phase were detected in these specimens. There appear to be two possible interpretations of these results. The films may have inhibited transformation at the surface but not in the interior, or the films may not have been continuous on the backs and edges of the specimen that could not be polished properly, and transformation may have occurred there.

The Habit Plane: The persistence of the relief effects on quenching from liquid nitrogen into mineral oil at room temperature greatly facilitated the determination of the lithium habit plane, for it meant that trace measurements could be made at room temperature. Orientations were determined by the back-reflection method using a precision camera designed to permit Laue patterns to be taken at previously selected positions on the specimen. To prevent the diffraction pattern of the base from appearing in the photograph, a plug of litharge-glycerin cement was inserted in the aluminum specimen holder. Crystals that passed completely through the specimen were selected to prevent the Laue patterns of underlying crystals, as well as of the crystal under investigation, from appearing on the film.

The method of determining the habit plane from the observed traces consisted of plotting the zone that was normal to each trace in a single stereographic triangle and determining the common point of intersection of all the zones. In this way an unambiguous solution for the habit plane could be obtained without making measurements of the traces of any single plate on more than one surface. The procedure is illustrated in fig. 4. Fourteen trace normals in four different crystals all passed within $\pm 1\frac{1}{2}°$ of the solution indicated in fig. 4. This plane, which is $10\frac{1}{2}°$ from (110) can be described approximately by the indexes $\{441\}_{\gamma\to\alpha'}$.

Discussion of Results

The result obtained for the lithium habit plane is of interest for several reasons. First, it is now clear that the observed habit plane is not that predicted by the Burgers' mechanism and that this mechanism will therefore have to be revised. Second, the observed habit plane is closely similar to the habit

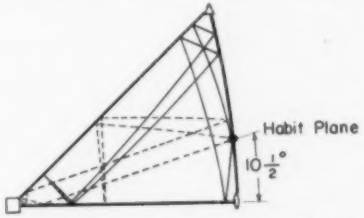

Fig. 4—Stereographic projection of the pole of the lithium martensite habit plane illustrating the method of determining the habit plane from trace measurements on single surfaces.

planes utilized in a number of other martensite transformations in body-centered cubic metals (table I). It seems reasonable to conclude from this recurrence of nearly the same habit plane for essentially equivalent transformations in quite different systems, that the choice of habit plane is determined by the geometry of the transformation mechanism rather than by other considerations.

The relief effects produced by the transformation consisted essentially of a simple tilting of the surface about its intersection with the habit plane. This means that the transformation involves a homogeneous distortion of the original structure, in which the habit plane is a plane of zero distortion. However, since the body-centered cubic structure is a space lattice with a single atom motif, it will remain

Table I. Habit Planes in Martensite Transformations

System	Transformation	Habit Plane
Cu-Al	b.c.c. → Distorted c.p.h. (β')[2]	{441}
Cu-Al	b.c.c. → c.p.h. (γ')[19]	{221}
Cu-Zn	b.c.c. → f.c.t. (?)[19]	{551}
Cu-Sn	b.c.c. → Structure unknown[20]	{331}
Au-Cd	b.c.c. → Orthorhombic[21]	{231}
Li	b.c.c. → c.p.h.	{441}

a space lattice with a single atom motif throughout any succession of homogeneous distortions. Clearly then, the observed change in structure cannot be achieved by the observed homogeneous distortion. Additional atom movements that do not cause any observable change in shape of the plate must also occur. The transformation b.c.c. → c.p.h. therefore involves two distortions of the original lattice, one homogeneous and the other heterogeneous. In this respect it is analogous to the f.c.c. → b.c.t. transformation that occurs in Fe-C alloys[6] and the f.c.c. → f.c.t. transformation that occurs in In-Tl alloys.[7]

Recent studies of these transformations have demonstrated clearly the nature of the problems involved in the determination of the crystallographic mechanisms of martensite transformations. It is necessary to decide first, what net atom displacements are needed to build up a unit cell of the new phase, and second, how this "unit distortion" is repeated throughout the parent lattice. The criterion of an acceptable mechanism is, of course, that it be consistent with all the geometrical features of the transformation, e.g., orientation relationships, habit plane, etc.

In the Fe-C and In-Tl transformations, the net atom displacements that occur are those that lead to the smallest overall distortion of the parent lattice. That this is also true for at least one of the b.c.c. → c.p.h. transformations is indicated by the work of Kurdjumow and Miretsky[8] who have shown that the assumption of minimum overall distortion leads to a prediction of the observed superlattice in Cu-Al martensite. Since these minimum displacements are exactly those proposed by Burgers, it seems very likely that the Burgers' mechanism is correct as far as the displacements in any small region are concerned.

If this conclusion is correct, then to modify the Burgers' mechanism so that it becomes consistent with the observed habit plane and relief effects necessitates a consideration of the manner in which this unit distortion is repeated throughout the lattice.

In the Fe-C and In-Tl transformations, the unit distortion is not repeated as a simple homogeneous distortion throughout the lattice. It is necessary to describe the correspondence between atom positions before and after transformation by two distortions, the first homogeneous and the second heterogeneous. The homogeneous component accounts satisfactorily for the observed habit plane and relief effects, and in the indium-thallium alloys for the observed propagation of the transformation distortions at an interface parallel to the habit plane. The heterogeneous component is necessary to complete the transformation, and accounts for the transverse markings that are seen in martensite plates. The problem of explaining the observed habit plane and relief effects in the b.c.c. → c.p.h. transformation probably has an analogous solution, but a geometrical analysis of the distortion indicated by the relief effects will be needed before a complete description of the transformation mechanism can be given. Since lithium is not a suitable material for such work, it will probably be simpler to carry out such an analysis for one of the other systems.

Summary

1. Techniques have been developed for the metallographic examination of lithium and the microstructural characteristics of lithium martensite are described.

2. The lithium habit plane has been shown to be approximately {441}. This is not in agreement with Burgers' prediction of {112} but is closely similar to the habit planes utilized in other martensite transformations in body-centered cubic metals.

3. The atom movements proposed by Burgers are probably correct for they are consistent with the observed superlattice in Cu-Al martensite. To modify Burgers' mechanism so that it becomes consistent with the observed habit plane and relief effects, it will be necessary to find out how the "Burgers' unit distortion" is repeated throughout the lattice.

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Plastic Deformation and Diffusionless Phase Changes In Metals — The Gold-Cadmium Beta Phase

by L. C. Chang and T. A. Read

Diffusionless transformation in Au-Cd single crystals containing about 50 atomic pct Cd was investigated by means of X-ray analysis of the orientation relationships, electrical resistivity measurements, and motion picture studies of the movement of boundaries between the new and old phases during transformation. The nucleation of diffusionless transformation by imperfections and the generation of imperfections by diffusionless transformation were discussed.

THAT connections exist between plastic deformation and diffusionless phase changes has long been recognized. Thus it is often possible to produce a diffusionless phase change in a temperature range, above that in which the change occurs spontaneously, by cold-working the initial phase.

Certain aspects of the dislocation theory of the plastic deformation of crystalline solids also provide for a rather direct connection between the processes involved in plastic deformation and in diffusionless phase changes. Heidenreich and Shockley[1] have pointed out that simple edge dislocations in f.c.c. metals are probably unstable, and that the more probable lattice imperfections, called extended edge dislocations, consist of two half dislocations separated by a distance of the order of magnitude of 100A. The region about two atomic planes thick between the half dislocations because of this stacking fault may be described as having the hexagonal close-packed structure. Presumably the stacking faults observed by Barrett[2] after cold-working f.c.c. Cu-Si alloys resulted from the passage of such half dislocations through the lattice of the initial phase.

It is now becoming clear that the development of a detailed theory of the atomic movements involved in diffusionless phase changes will require a consideration of the role played by lattice imperfections, just as such considerations are necessary to the understanding of plastic deformation mechanisms. This point of view has been recently set forth, for example, by Cohen, Machlin, and Paranjpe[3] who pointed out the role which might be played by screw dislocations in nucleating diffusionless phase changes.

The present paper reports on some aspects of the diffusionless phase change in single crystals of the beta phase alloy Au-Cd which serve to emphasize further the importance of lattice imperfections in diffusionless phase changes.

The diffusionless phase change of Au-Cd possesses several remarkable features. One of these is that the interface between the high-temperature beta phase and the low-temperature orthorhombic phase typically moves with a low velocity, in contrast to the behavior observed in the transformation of austenite to martensite. Motion pictures of this slow interface motion have been prepared in the course of the work reported here.

Another important feature of the Au-Cd transformation is the small amount of undercooling observed. The reverse transformation occurs on reheating to a temperature only 20° higher than the transformation temperature observed on cooling, and under some circumstances the hysteresis observed is substantially less than this. This narrow temperature range between transformation on heating and cooling is presumably in part a consequence of the fact that the transformation requires a lattice shear of only about 3°.

Finally, the orthorhombic product phase possesses unusual mechanical properties, as was first pointed out by Olander[4] and Benedicks.[5] After completion of the transformation on cooling the specimen can be severely deformed, yet on the release of load it springs back to its original shape in a rubber-like manner. Explanation of this phenomenon will require an understanding of the lattice imperfections in the orthorhombic structure and, correspondingly, of those in the initial body-centered cubic structure.

Single crystals of Au-Cd alloy containing 47.5 and 49.0 atomic pct Cd were prepared from fine gold (99.95 pct purity) and chemically pure cadmium (99.99 pct purity) by melting the alloy in an evacuated and sealed fused quartz tubing and growing into single-crystal form by the Bridgman method. The Au-Cd alloy containing 47.5 atomic pct Cd undergoes a diffusionless transformation from an ordered body-centered cubic structure to an orthorhombic structure when it is cooled to about 60°C, while the reverse transformation takes place when the alloy is heated to about 80°C, according to electrical resistivity studies. The structures of these two phases have been studied by Olander,[4] reinvestigated by Bystrom and Almin.[6] The lines of Debye photogram of powdered samples of Au-Cd alloy containing 47.5 atomic pct Cd prepared in this laboratory were identified and agreed fairly well with those of

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Olander. The crystal structures of the two phases are as follows:[7]

High-temperature phase (β_1):
CsCl structure, 2 atoms per unit cell, ordered. $a = 3.3165 \pm 0.0005$ kX units.

Low-temperature phase (β'):
Orthorhombic, $a = 3.1476$, $b = 4.7549$, $c = 4.8546$, ± 0.0005 kX units.

Two Cd atoms approximately located at 0,0,0 $0,\frac{1}{2},\frac{5}{8}$

Two Au atoms approximately located at $\frac{1}{2},0,\frac{1}{2}$ $\frac{1}{2},\frac{1}{2},\frac{1}{8}$.

The Au-Cd alloy containing 49.0 atomic pct Cd undergoes a diffusionless transformation from the ordered body-centered cubic structure to a tetragonal structure[7] when it is cooled to about 30°C; and the reverse transformation typically takes place when the alloy is heated to about 40° to 55°C, depending on the previous history of the alloy. The structural details of the tetragonal phase are not known.

Experimental Procedure

The back-reflection Laue method was used to determine the orientations of the single crystal β_1 phase. The specimen was fixed in a holder provided with means of heating and cooling the specimen without disturbing its position. By this means the orientation relationship between the β_1 and β' phases was determined. The transformation markings and the plane of moving interface between the β_1 and β' phases during transformation were determined by measuring the traces of the markings across two flat surfaces perpendicular to each other.

The change in resistivity of the Au-Cd single crystals on cooling and heating through the transformation temperature range with and without applied stress was studied. The measurements were obtained by setting the sample in a wedge against two knife edges. A current of about 5 amp was sent through the sample and the voltage drop between the knife edges was measured by a Leeds and Northrup K-2 potentiometer. The current going through the sample was measured by placing a calibrated shunt in series in the circuit and measuring the voltage drop across the shunt with another K-2 potentiometer.

The orthorhombic β' phase possesses a characteristic pseudo-rubberlike behavior. The stress-strain curves of this phase within the quasi-elastic range were also obtained.

Motion pictures, taken at a magnification of 100 diam, were prepared which reveal the changes in surface contour of a metallographically polished single-crystal specimen containing 47.5 atomic pct Cd. These changes in contour make it possible to follow the motion of the interface between the new and old phases, both on heating and on cooling.

Results

Orientation Relationships: The orientation relationships between the β_1 and β' phases of the Au-Cd single crystal containing 47.5 atomic pct Cd, from several independent determinations from back-reflection Laue patterns, were found as follows:

$$(011)_{\beta_1} \text{ parallel to } (001)_{\beta'} \text{ (planes)}$$

$$[\bar{1}\bar{1}1]_{\beta_1} \text{ parallel to } [\bar{1}\bar{1}0]_{\beta'} \text{ (directions).}$$

Transformation Markings and Moving Interfaces: In general, a single crystal of the cubic high-temperature phase β_1 does not transform on cooling to a single crystal of the low-temperature phase β'. Instead, the sample is found after transformation to consist of an aggregate of crystals of the low-temperature phase. The relative orientations of these crystals correspond to the various crystallographically equivalent transformation lattice shears. Thus, in general, the transformation of the single-crystal specimen as a whole is inhomogeneous. This is clearly shown by the fact that if a polished flat surface is prepared on the specimen while it is hot, and thus has the cubic structure, this surface is no longer plane after transformation to the orthorhombic structure. If the transformation occurred in a completely homogeneous way, the plane surface of the cubic crystal should remain plane and free of surface markings after transformation. These heterogeneous transformation strains are, however, completely reversed on reheating to the cubic phase. The strain markings disappear and the originally plane surface becomes plane again. In the following this will be referred to as a "multiple interface transformation."

In the present work success has been achieved in producing a transformation from the cubic to the orthorhombic phase by the motion of a single interface. In this case transformation starts at one end of the cubic single-crystal specimen, and then, on continued cooling, the interface between the two phases is translated toward the other end of the specimen. The shear character of the transformation is readily apparent from the appearance of the specimen after partial transformation; the flat surface on the original cubic crystal has become two plane surfaces which intersect in a sharp corner at the interface, and the dihedral angle agrees with that predicted from the lattice shear value from the X-ray diffraction observations. After complete transformation to the orthorhombic structure no strain markings are visible on the polished surface of the sample. This will be referred to here as a "single interface transformation."

The pre-treatment of the crystal sample required to achieve the homogeneous transformation described above includes an anneal of several days a few degrees below the solidus temperature.

The plane of the interface between the two phases during single interface transformation is the (331) of the cubic phase, within the experimental error of approximately 2°.

Reversible Orientation Relationships: During the determination of orientation relationships of the transformation, it was invariably found that when a single crystal of β_1 transformed by the multiple interface mechanism into a crystal aggregate of β', on reverse transformation a single crystal of the initial orientation was obtained. The same phenomenon was also observed in the Au-Cd single crystal containing 49.0 atomic pct Cd.

Resistivity Measurements: The change in electrical resistivity of the Au-Cd single crystal (containing 47.5 atomic pct Cd) on cooling and reheating through the transformation temperature range

Table I. Temperature of Beginning Transformation

	Cooling, °C		Heating, °C	
No stress	M'_s	61.0	M'_s	73.5
Under stress	M_s	64.0	M_s	66.0

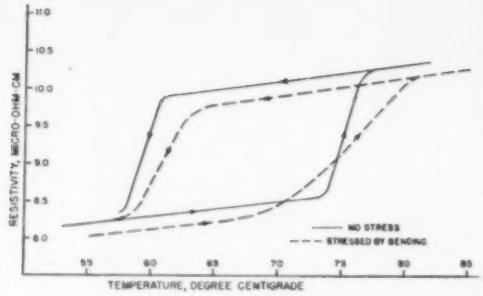

Fig. 1—Resistivity-temperature curve for single crystal Au-Cd alloy containing 47.5 atomic pct Cd.

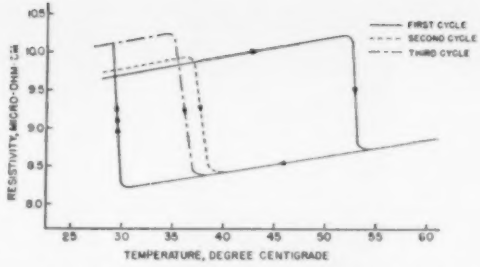

Fig. 2—Resistivity-temperature curve for single crystal Au-Cd alloy containing 49.0 atomic pct Cd.

with and without stress, is shown in Fig. 1. The stress was applied by bending the specimen (approximately $\frac{1}{8}$ in. sq in cross-section) 0.1 in. (maximum displacement measured at the middle of the specimen) over a span of about 1.5 in. The temperature of beginning of transformation, according to Fig. 1 with and without stress, is summarized in Table I.

The change in electrical resistivity of the Au-Cd single crystal (containing 49.0 atomic pct Cd) on repeated cooling and reheating through the transformation temperature range is shown in Fig. 2. Figs. 1 and 2 were both obtained under conditions of multiple interface transformation.

The electrical resistivity of the 47.5 pct Cd alloy decreases on transformation to the orthorhombic phase while the electrical resistivity of the 49.0 pct Cd alloy increases on transformation to the tetragonal phase.

Stress-Strain Curves: A typical load-deformation curve in the bending test of a specimen transformed (multiple interface) from a single crystal of Au-Cd alloy containing 47.5 atomic pct Cd is shown in Fig. 3. The load was applied at the middle of the specimen about $\frac{1}{8}$ in. sq in cross-section over a span of about 1 in. The load in pounds was plotted against maximum deflection in inches in Fig. 3. The load P, maximum deflection Y, modulus of elasticity E, moment of inertia I, and the length of specimen between the two supports l, are related by the following equation:

$$Y = \frac{-Pl^3}{48EI} \qquad [1]$$

The effective modulus of elasticity E of the β' specimen at different stages of bending was calculated according to eq 1 from the respective $\Delta P/\Delta Y$ values evaluated from the slopes of the small hysteresis loops (see Fig. 3). The calculated E values are summarized in Table II.

Motion Pictures of Interfaces: Motion picture studies of the appearance and motion of interfaces between the β_1 and β' phases during transformation were made. These studies included specimens in which the transformation was of the single-interface as well as the multiple-interface kind.

In the case of multiple-interface transformation, plates of the orthorhombic phase appear abruptly during cooling through the transformation range, as is shown in Fig. 4. The rate of formation of these plates is shown here in a succession of four frames from the movie film. The black line extending from

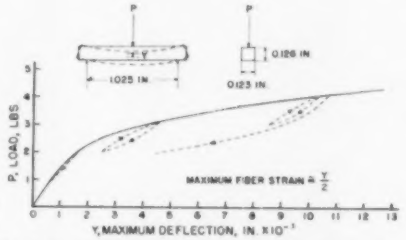

Fig. 3—Load-deflection curve of β' Au-Cd alloy containing 47.5 atomic pct Cd.

the center of the field vertically upward to the periphery is a reference line not belonging to the specimen. No plate extends across the reference line in Fig. 4*a*. The next frame (Fig. 4*b*) shows the formation of one plate. The third frame (Fig. 4*c*) shows the formation of a second plate. In later frames, shown in Fig. 5, these plates grow in thickness and other plates appear which are not parallel to those shown in Fig. 4, until the specimen is apparently completely transformed.

The substantially different state of affairs with the carefully annealed crystal is illustrated in Fig. 6, in which is shown a plane interface between the two phases in a partly transformed crystal. This interface extends completely out to the free surfaces of the specimen. In this case the interface geometry undergoes no obvious change as the transformation proceeds. Correspondingly, the amount of transformed material increases fairly smoothly with time as the specimen temperature is changed. Even in this case, however, there are perceptible irregularities in the interface motion, which are more pronounced for the transformation on heating than on cooling. This homogeneous transformation by slow

Table II. Calculated Values of Modulus of Elasticity of Specimen β'

Load, Lb	Maximum Deflection of Specimen, In.	Maximum Fiber Strain	E*, Psi
0	0	0	1.5×10^6
2	0.0015	0.00075	1.1×10^6
3	0.0045	0.00225	0.55×10^6
4	0.0104	0.0052	0.61×10^6
6	0.0345	0.0173	0.66×10^6

* Effective modulus of elasticity averaged over the cross-section of the specimen.

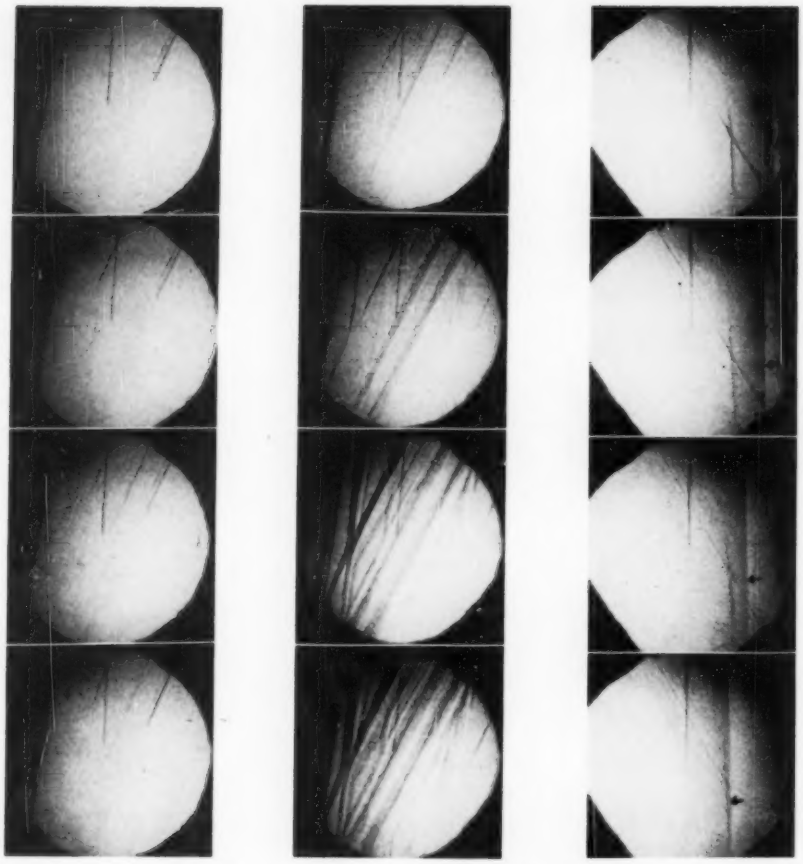

Fig. 4 (left)—Four successive frames showing the formation of β' plates.

Printed from a movie taken at a speed of 32 frames per sec. X100. *a* (top) first frame. *b* (second from top) 1/32 after first frame. *c* (second from bottom) 1/16 sec from first frame. *d* (bottom) 3/32 sec from first frame.

Fig. 5 (center)—Continuation of Fig. 4 showing inhomogeneous transformation of β_1 to β'.

X100. *a* (top)—10th frame. *b* (second from top)—30th frame. *c* (second from bottom)—90th frame. *d* (bottom)—130th frame.

Fig. 6 (right)—Prints taken from a movie film (made at a speed of 32 frames per sec) showing the single interface transformation of β_1 and β'.

Moving interface is marked by arrow head. X100. *a* (top)—1st frame. *b* (second from top)—12th frame. *c* (second from bottom)—23rd frame. *d* (bottom)—34th frame.

Figs. 4-6. Area reduced approximately 50 pct in reproduction.

movement of an interface between the two phases is not to be confused with isothermal transformation. The interface moves under the condition that the temperature of the specimen is continuously changing. Preliminary measurements show that the rate of movement of the interface is almost directly proportional to the rate of change of temperature of the specimen. Another phenomenon observed in the case of single-interface transformation is stabilization. When, for instance, the temperature of the specimen is arrested on heating, the interface movement stops and no further transformation occurs until the specimen is heated to a slightly higher temperature than the temperature of arrest.

Discussion

Mechanism of β_1-β' Transformation: The atomic movements and crystallographic mechanism involved in the β_1-β' transformation of the Au-Cd alloy containing 47.5 atomic pct Cd will be separately discussed in another paper.[17] The crystallographic mechanism was experimentally evaluated as a simple homogeneous shear $(\bar{3}31)_{\beta_1}\ [323]_{\beta_1}$ of about 3° plus a possible homogeneous contraction of about 0.015 *kX* units along the *b*-axis of the orthorhombic cell. This crystallographic mechanism yields almost exact agreement between the calculated and experimentally measured values of the cell dimensions of the orthorhombic phase.

Nucleation: The effect of stress on the temperature of beginning of transformation illustrated in Fig. 1 shows that nucleation in this diffusionless transformation is strongly influenced by the state of stress present in the specimen. Although the effect of stress on transformation has been discussed

by several investigators, such as Scheil[7] and McReynolds,[8] the data shown in Fig. 1 are the only available data demonstrating the effect of stress during a whole hysteresis cycle.

According to Fig. 1 the effect of the stress distribution on the transformation on heating is somewhat different from its effect on the transformation on cooling. In the first case transformation starts at a lower temperature but goes to completion at a higher temperature than in the stress-free case. On cooling, however, the transformation starts at a higher temperature but goes to completion at approximately the same temperature as it does for the same specimen not under stress. This difference between the effects of stress on the $\beta_1 \rightarrow \beta'$ and the $\beta' \rightarrow \beta_1$ transformations can be understood if one considers that a shear stress cannot oppose the transformation from cubic to orthorhombic, but can oppose the reverse transformation. Corresponding to any particular plane and direction of transformation shear, it is possible for the cubic to orthorhombic transformation to occur on the same plane but in the reverse direction. Thus if an applied shear stress opposes transformation in one of these directions, it must aid transformation in the other.

Because of the lower symmetry of the orthorhombic phase, transformation to the cubic phase by simply reversing the direction of shear on a particular plane cannot occur. Now since the specimen on which the data of Fig. 1 were obtained had originally been transformed to the orthorhombic phase by the multiple interface mechanism with no applied stress, the variously oriented regions of orthorhombic phase included some so oriented that the applied stress aided the reverse transformation. These regions accounted for the beginning of transformation at a lower temperature than that observed when no stress is applied to the specimen. Conversely, regions of the orthorhombic phase so oriented that the applied stress opposed the transformation shear transformed at a higher temperature than when no stress is applied. This discussion is, of course, based on the premise that the original cubic single crystal is produced by the orthorhombic to cubic transformation, as has always been observed in this investigation.

On the basis of the above discussion it might be expected that loading the specimen in bending would raise not only the temperature at which the transformation starts on cooling but also the temperature at which it goes to completion. On the other hand, near the neutral axis the stress is low, and correspondingly the material located here will transform at essentially the same temperature as when no stress is applied.

This interpretation of the effect of stress on the transformation characteristics is supported by the observation that was made that a straight rod of the cubic phase acquired a permanent set if it was cooled through the transformation under stress. This permanent set disappeared and the specimen again became straight when reheated to the cubic phase, even when the specimen was still stressed in bending.

Perhaps the most important evidence that this diffusionless transformation is nucleated by residual stresses, or certain types of imperfections, lies in the fact that a specimen which transforms with many interfaces may be made to transform with a single interface (i.e., the formation of an interface at one end of the specimen and movement of this interface toward the other end of the specimen until complete transformation) by long annealing. Second, a specimen which transforms with a single interface may lose this characteristic by improper handling, only to be brought back again by annealing. These phenomena cannot be readily interpreted by the thermodynamic theory of embryo nucleation recently advanced by Fisher, Hollomon, and Turnbull.[10] It appears rather that the nucleation of the low-temperature phase on cooling is primarily dependent on the existence of imperfections in the specimen which perhaps had their origin in growth from the melt or in previous plastic deformation.

Transformation with a Single Interface: The transformation of a well-annealed single crystal of the 47.5 atomic pct Cd alloy by the motion of a single interface from one end of the specimen to the other represents a diffusionless phase change with the simplest possible geometry. The volume of stable phase grows at the expense of the unstable phase by the displacement of a single plane interface of unchanging area. One of the aspects of this transformation which must be accounted for is the fact that it does not proceed isothermally, and, in fact, if a partly transformed specimen is held at constant temperature the interface becomes stabilized against further displacement.

It appears that some relaxation process occurs at or near the interface which lowers the interfacial energy and thus the free energy of the sample. Before this relaxation occurs the free energy of the specimen at constant temperature is a straight-line function of the amount transformed and hence of the position of the interface. After relaxation the graph of free energy as a function of interface position possesses a relative minimum at the actual position of the interface.

This behavior might be likened to the rolling of a steel ball down an inclined plane which is coated with a soft material into which the ball sinks. The ball becomes stuck unless it is rolling rapidly. In the transformation experiments discussed in this paper, however, a rapid motion of the interface is precluded by the latent heat of the phase change. Since the transformation is observed at a temperature only about 10° from the thermodynamic equilibrium temperature at which the bulk free energies are equal, rapid and hence adiabatic transformation is not possible. An upper limit to the rate of transformation is set by the rate at which the latent heat is conducted away. No direct evidence as to the nature of this relaxation process at the interface has yet been obtained.

Imperfections Caused by β_1-β' Transformation: A typical back-reflection Laue photogram of a β' specimen transformed by the motion of a single interface from a single crystal of β_1 is shown in Fig. 7. The spots seem to be sharp and the Laue zones are rather well defined.

In the case of complex transformation with many interfaces, however, the formation of differently oriented regions (see Fig. 5) will give rise to misfits at places where these regions meet. The strain due to these misfits or imperfections presumably causes the phase to follow the opposite path on its reverse transformation to the β_1 phase, as is experimentally observed.

The generation of imperfection in the low-temperature phase by diffusionless transformation is reflected in the electrical resistivity data shown in

Fig. 7—Back-reflection Laue photogram of β' crystal transformed with a single interface from a single crystal of β_1. X-ray beam almost parallel to [111] direction of β'.

Fig. 2 for the Au-Cd alloy containing 49.0 atomic pct Cd: the electrical resistivity of the tetragonal low-temperature phase at a given temperature increases successively after each transformation cycle while the temperature of the reverse transformation to β_1 phase decreases successively after each transformation cycle. Both the electrical resistivity of the high-temperature β_1 phase (at a given temperature) and the temperature of transformation into tetragonal phase, however, remain unchanged by cyclic cooling and reheating. The electrical resistivity of the tetragonal phase after transformation decreases slowly with time (finally reaching a stabilized value), meanwhile the temperature of reverse transformation to the β_1 phase increases, indicating that the imperfections generated in the tetragonal phase become less effective in nucleating the reverse transformation. A similar phenomenon was also observed in the Au-Cd alloy containing 47.5 atomic pct Cd.

The rubberlike properties of the β' orthorhombic phase may be seen from the stress-strain curve shown in Fig. 3. First, it has an extraordinarily low effective modulus of elasticity, about 1×10^5 psi; and, second, the effective elastic modulus increases slowly with increasing stress. The most probable explanation of this rubberlike behavior of the orthorhombic phase when it consists of variously oriented regions, all transformed from one cubic single crystal, appears to be that it represents displacement of the interfaces between the differently oriented regions. This displacement is in such a direction that favorably oriented regions increase in size at the expense of less favorably oriented ones. In this connection, "less favorably oriented" means so oriented that the applied shearing stress tends to shear the region back toward the high-temperature cubic structure. When observed under the microscope during bending, changes in surface contour are seen that can be interpreted as interface displacements of this kind.

When the stress applied to the specimen is released, the boundaries between the variously oriented regions return to their original positions and the specimen regains its original shape.

The origin of the force which makes the interfaces return to their original positions probably is related to a relaxation process which occurs at or near the interfaces between the differently oriented regions. This relaxation process may be essentially the same as that discussed above with reference to the motion of the single interface between the two phases. Additional evidence for this relaxation process is furnished by the observation that immediately after a specimen has been transformed to the orthorhombic phase it is not rubberlike, but is very soft and takes a permanent set. Apparently the boundaries between the differently oriented regions stay in their new positions after the release of the applied stress if they are moved before the relaxation occurs. This permanent set is recoverable, however, for it disappears as the specimen is transformed back to the cubic phase.

The rubberlike behavior was not found in the low-temperature tetragonal phase of the Au-Cd alloy containing 49.0 atomic pct Cd. Apparently this behavior is characteristic of the orthorhombic β' phase.

Summary and Conclusions

The mechanism of diffusionless transformation in Au-Cd single crystals containing about 50 atomic pct Cd was investigated by means of X-ray analysis of the orientation relationships, electrical resistivity measurements, and motion picture studies of the movement of boundaries between the new and old phases during transformation. The mechanism of diffusionless transformation and the generation of imperfections by diffusionless transformation were discussed. The results of this study also suggest the need of further investigation of the nature of imperfections present in the parent alloy and the type of imperfections generated in the product by diffusionless transformation.

Acknowledgments

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Atomic Relationships in the Cubic Twinned State

by W. C. Ellis and R. G. Treuting

The twinned state is characterized by a lattice of coincidence sites. Imperfections are required at stable lateral twin interfaces. Twinned regions can occur with relative ease in the diamond cubic structure.

IN recent contributions[1,2] on the origin and growth of cubic annealing twins, attention has been directed to the orientation relations between such twinned components and their parent matrix. There are some aspects of twinning which may be illuminated by a more detailed consideration of the twinned state[3] alone. As an extreme example, the dense twinning in cast ingots of germanium,[4] as contrasted with the rarity of twins in cast face-centered cubic metals, is yet to be accounted for. It has been this that has led us to the present work, which, it will be noted, uses methods and constructions in many respects similar to those of Kronberg and Wilson.[1]

In the cubic systems, a 70° 32′ rotation about a <110> axis is angularly equivalent, as to twinning, to the more usually considered 180° rotation about a <111> axis. Figs. 1 and 2 show a (110) projection of a twinned face-centered cubic lattice and a twinned diamond cubic lattice. In both figures, the two adjacent planes *A* and *B*, shown by the larger and smaller circles, are sufficient to represent the entire array. In each case a section of lattice, the original atom sites of which are shown by open circles, has been rotated as indicated through 70° 32′ to bring an original $[\bar{1}12]$ direction into coincidence with the $[1\bar{1}2]$ direction. The latter is the intercept on the (110) projection of the $(\bar{1}11)$ plane normal thereto, the twinning plane. In the face-centered cubic case the rotation can be performed about an axis passing through an atom-site; the mirror plane then is also a composition plane containing atoms common to both twinned and untwinned lattices.

The diamond cubic lattice may be construed as two interpenetrated face-centered lattices. Its {111} planes recur in a sequence of alternately short and long interspacings. Consequently a mirror plane for twinning cannot be a composition plane, but must be the bisector of one of the spacings. When the longer spacing is selected, the closest distance of approach across the mirror plane in the $[\bar{1}11]$ direction is identical with that in the untwinned structure.

In each case periodically recurring $(\bar{1}11)$ planes (parallel with the twinning plane) are found, on which there is coincidence of atom sites of the pretwinned and twinned orientations; these are indicated by the cross-hatched circles. In the face-centered lattice there is such coincidence every third $(\bar{1}11)$ plane; in the diamond cubic lattice, on two adjacent planes in every six. At the twinning interface in the latter, there is on each side of the mirror plane a $(\bar{1}11)$ plane of atoms common to both twin components. Conceivably, there is little influence on a plane of atoms about to be adhered to such a pair of coincidence planes, whether it be laid down in a normal or in a twinned position with respect to the previously formed structure. Slawson[5] has attributed the high incidence of twinning in diamond to this boundary state.

Further examination shows that the motion of intermediate planes can consist of various pairs of equal and opposite translations, for example of $(\bar{1}11)$ planes in the $[\bar{1}\bar{1}2]$ direction, the familiar twinning shear, indicated in the small schematics in the figures. Since the translations form a system of shears of alternating sign between coincidence planes, twinning could take place by such a mechanism over an extended region without extensive shear; in fact, in this case any atom moves but the distance $a_o/\sqrt{6}$ in the $[1\bar{1}2]$ direction. One alternative construction for the face-centered cubic lattice leading to the same end result is illustrated in Fig. 3. The plane $(\bar{1}11)$ with respect to the pretwinning orientation (the twinning plane of Fig. 1) is given, the twinned region arbitrarily bounded by <110> and <112> directions. The coupled shear is identical to that of Fig. 1. The "rotational" movement about coincidence sites generating the same twinned position could consist as shown of the translation $a_o/\sqrt{6}$ for each atom of a group of three in the *B* layer in a different one of the three <112> directions, and a similar translation of the underlying three atoms in the *C* layer in either the same or the opposite sense. This is not dissimilar to Kronberg and Wilson's construction for their 22° rotation of three adjacent {111} planes.

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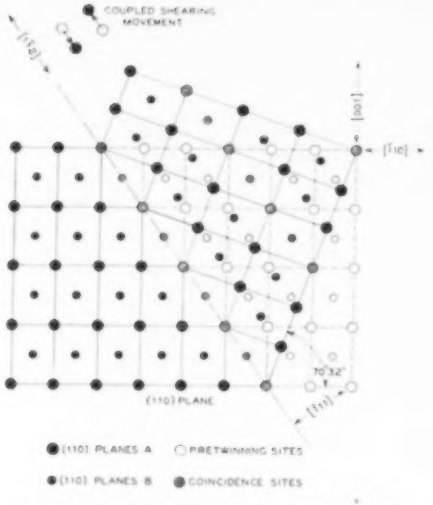

Fig. 1—Face-centered cubic twinning, (110) projection.

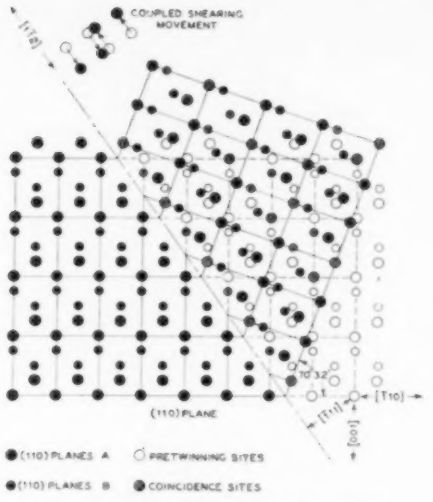

Fig. 2—Diamond cubic twinning, (110) projection.

On examining the body-centered cubic case, we find an analogous situation: The projection on the (110) plane is given in Fig. 4. The $(\bar{1}12)$ twinning plane shows coincidence of sites every third layer, with a system of translations which can be coupled in one manner or another to balance within a six-layer identity period. Although there is a coincidence plane every third layer from the twinning plane, these belong alternately to (110) plane sets *A* and *B*.

The Coincidence Site Superlattice

If the projections of twinning in the three cubic systems are examined further, it is found that in each case the twinning plane and a system of others parallel thereto are not the only planes of coincidence sites. There is in each twinned region a superlattice of atom sites common to the pre- and post-twinned orientations.

In the face-centered cubic lattice, Fig. 1, the $(\bar{1}12)$ plane perpendicular to the twinning plane and to the plane of projection has periodic recurrence of coincidence sites and the same index type in each portion of the twin. These properties are also possessed by the other two {112} and the three {110} planes perpendicular to the twinning plane. A stereographic twinning operation also shows polar coincidence between certain {221} planes of the pretwinned orientation and {100} of the twinned, and vice-versa; and between respective {511} and {111} planes and vice versa, among others. Under the assumed atomic relationship, these planes are also periodically atomically coincident. In such cases the difference in atomic density dictates that not all the sites of one orientation can belong likewise to the other. Thus, in Fig. 1 the (111) plane of the twinned region coincides with the sparsely populated $(1\bar{1}5)$ of the pretwinning orientation. Obviously, only occasional atoms of the former can occupy sites on the latter, but all such sites are so occupied.

The coincidence site superlattice is no more than a possible description of the twinned state in the cubic systems, the coupled shear mechanism a suggestion as to how this state may under some circumstances be attained. Since the mechanism results in a perfect twinning relationship, it would not apply in the case of nucleation from a distorted matrix.[3] It would be a possible mode of twin growth in the course of grain growth following recrystallization only if the twin interface migrated with increasing grain size. Recent evidence by Burke[4] is in opposition to a twin interface migration. Two phenomena demonstrated by Burke, however, may be rationalized by the proposed mechanism: One of these is coalescence, in effect a detwinning mechanism; and the other the rectification of stepped twin boundaries† apparent in Burke's photographs. Each of these effects could be produced by a lateral propagation of the coupled shear mechanism in a direction to minimize the twin boundary area.

Lateral Interfaces of Twins

In each of these cases, also, the twin has other boundaries than the twinning plane or a grain boundary. Lateral, or incoherent, boundaries are in general straight and, when enough appear in one grain, show few and preferred directions. Hence, they are probably crystallographic planes forming relatively stable interfaces. An interface of this nature might be supplied by any of the planes of the coincidence site superlattice. Each of these is occupied by atoms common to the lattices of both orientations; across such there may be a more or less disperse aggregation of atomic juxtapositions requiring readjustment to satisfy nearest neighbor distance requirements.

Thus, if as in Fig. 3, a twinned region be projected on a {111} twinning plane and bounded from the untwinned material by planes of the {110} and {112} types (normal to and intersecting the (111) projection plane in <112> and <110> directions respec-

† Observed by Burke. We are indebted to Dr. Burke for the opportunity to read his manuscript prior to publication.

tively), then the three {112} planes are seen to consist completely of coincidence sites, and atoms paired across this plane lie $a_o/\sqrt{6}$ mutually distant. The three {110} planes are but 1/3 populated by coincidence sites and the remaining atoms are at the $a_o/\sqrt{6}$ distance from their nearest neighbors in the untwinned region. (Greninger[7] has reported a {110} lateral twin boundary in copper.)

From the atom displacement it appears that, in twinning a perfect lattice, this close juxtaposition must be realized across any lateral boundary plane in the absence of any relieving mechanism. Since the $a_o/\sqrt{6}$ interatomic spacing corresponds to a compressive strain of 0.423 from the normal distance of closest approach, it is plausible to consider that this circumstance does not in fact occur. Accepting this as an hypothesis, we are led to the conclusions:

Crystallographic lateral twin boundaries are sites of lattice imperfections to relieve the violation of nearest neighbor requirements otherwise occurring there. Lateral twin growth will tend to proceed until an advancing boundary generates or encounters a sufficient concentration of lattice imperfections to permit a relatively stable interface. The most probable lateral twin boundary is that requiring a minimum number of lattice imperfections to render it relatively stable. This condition is approached by a crystallographic interface having a maximum frequency of coincidence sites and a minimum frequency of nearest neighbor distance violations, but planes meeting the one criterion do not in general tend to satisfy the other.

Remarkably, this close atomic juxtaposition across potential lateral twin boundaries seems to be avoided in the diamond cubic lattice. If now in Fig. 2 we consider the twinned region to be further bounded by a $(1\bar{1}2)$ plane passing through coincidence sites, the closest approach of atoms in the twinned and untwinned material across this boundary is again

Fig. 3—Face-centered cubic twinning, ($\bar{1}$11) projection.

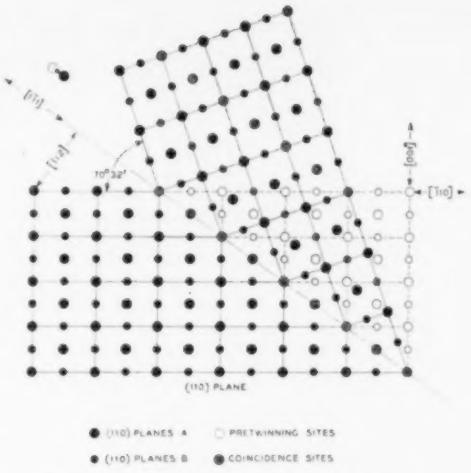

Fig. 4—Body-centered cubic twinning, (110) projection.

$\frac{a_o}{\sqrt{6}}$. The normal closest approach in this structure is $\frac{a_o\sqrt{3}}{4} = 0.433\ a_o$; the strain between atoms across such a lateral twin boundary is but −0.058. However, under this construction atoms on the coincidence plane have alternately three and five nearest neighbors, a circumstance that presumably requires some adjustment and consequent strain along such a boundary. Yet the favorable trans-boundary spacing, together with the double layer of coincidence sites at the twin plane in the diamond lattice, one is inclined to associate with the multitudinous twins found in cast silicon and germanium.[4]

Summary

Twinning in cubic metals can be the result of small atom displacements of a fraction of an interatomic distance on planes lying within a coincidence site superlattice. No extensive shear is required.

Imperfections are required in a stable lateral twin boundary in order to satisfy nearest neighbor distance requirements across such boundaries.

A double layer of coincidence sites along twin planes and a favorable lateral (or incoherent) trans-boundary spacing in the diamond cubic lattice predisposes materials having this structure to twinning.

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Transitions in Chromium

by M. E. Fine, E. S. Greiner, and W. C. Ellis

Discontinuous changes of Young's modulus, internal friction, coefficient of expansion, electrical resistivity, and thermoelectric power are evidence for a transition in chromium near 37°C. Although the X-ray diffraction pattern gives no clue, a difference between the thermal expansivity and the temperature dependence of the lattice parameter suggests a crystallographic change. Young's modulus data disclosed another transition near −152°C.

THE thermal dependence of a number of properties of chromium indicates a transition occurring over a temperature range near room temperature. Bridgman[1] noted this first from a minimum in the electrical resistivity near 12°C. In a sample of greater purity, Söchtig[2] observed the minimum at 41°C. Erfling[3] reported an inflection in the thermal expansivity curve at 36°C. These temperature-dependence curves are reversible with no hysteresis being detected. No discontinuity or inflection has been observed in the heat capacity[4] or the paramagnetic susceptibility.[5] Likewise, no one has noted a change in crystal symmetry.[6]

In the present investigation Young's modulus, internal friction, coefficient of expansion, electrical resistivity, illustrated in Fig. 1, lattice constant, Fig. 2, thermal electromotive force, Fig. 3, and paramagnetic susceptibility, Fig. 4, were measured over an extended temperature range.

The samples were prepared in two ways: (1) By cold pressing a sintered electrolytic powder compact,[7] and (2) by electroforming from an aqueous solution. The electroformed samples were prepared by R. A. Ehrhardt and G. Bittrich by plating on copper or nickel tubes from an aqueous solution according to the method of Brenner, Burkhead, and Jennings.[8] The pressed powder samples (method 1) were finally annealed at 1400°C in purified helium; the electroformed samples, packed in powdered chromium, were vacuum-annealed at 1000°C.

From the composition of the original powder[7] the purity of the pressed powder samples is estimated to be 99.8 pct Cr. Spectrochemical analysis furnished by E. K. Jaycox, revealed only slight traces of impurities in the electroformed sample (less than 0.001 pct), neither iron nor nickel being detected. Chromium deposited by this method is reported to contain approximately 0.05 pct O.[9]

Methods and Data

Young's Modulus: For measurement of Young's modulus, an annealed, pressed powder sample, 0.114 x0.237x1.845 in., and an electroformed sample, 0.10 in. od, 0.01 in. id, and 1.86 in. long, were prepared. The resonant frequencies of the rod samples in forced longitudinal vibration were measured at a series of temperatures from −192° to 200°C by a method previously described.[6, 10]

Because the samples were nonferromagnetic, iron-silicon or molybdenum permalloy tips (0.013 in. thick) were soldered to the ends. The softening temperature of the solder limited the temperature of measurement. Young's modulus, E_T, of chromium at temperature, T, may be calculated from the resonant frequency of the composite rod, f_T; the thickness of the tips, t; the length of the chromium sample at 25°C, l_c; the density of chromium at 25°C, ρ_c (7.20 g per cc);[11] and the thermal expansivity, $\Delta l/l_\infty$. Modulus differences for two temperatures, E_T and E, are accurate to $\pm 0.002 \times 10^{12}$ dynes per cm^2.

$$E_T = 4\rho_c (l_c + 2t)^2 f_T^2 \left(1 - \frac{\Delta l}{l_\infty}\right)$$

Young's modulus at 25°C, Fig. 1*a*, is 28.2×10^{12} dynes per cm^2 (40.8×10^6 psi) in wrought chromium (upper curve). The modulus of the electroformed sample is apparently lower due to cracks. From the modulus measurements two transitions were observed: one with a critical temperature at 37°C, the other at −152°C.

Internal Friction: The internal friction, $1/Q$, was determined from the width, Δf, of the strain amplitude-frequency curve at 0.707 times the strain amplitude at resonance;[7] the internal friction, $1/Q$, then equals $\Delta f/f$. Fig. 1*b* shows a sharp peak in internal friction at 38°C. The internal friction of the electroformed sample had a similar maximum.

Thermal Expansion: The expansivity measurements, shown in Fig. 2, covering the temperature range −195° to +400°C were made by D. MacNair in an interferometric dilatometer[6] using a sample consisting of three pyramids 0.25 in. high prepared from wrought electrolytic chromium. Below −120°C the experimental points deviated up to $\pm 2 \times 10^{-6}$ from the drawn expansivity curve in Fig. 2 because of decreased precision of the quartz wedge thermometer at low temperatures. Near 38°C the thermal expansivity curve, Fig. 2, goes through an inflection corresponding to a minimum in the coefficient of expansion, Fig. 1*d*, and a relative volume decrease on heating.

Electrical Resistivity: The variation of electrical resistivity with temperature measured by the potentiometric method is also shown in Fig. 1. The resistivity of the wrought chromium (upper curve) at 20°C is 13.6 microhm-cm; of electroformed chromium (lower curve) 12.8 microhm-cm. The lower value reflects higher purity and agrees closely with a published value.[6] A minimum at 40°C occurs in the resistivity curves of both samples. No conclusive evidence for a transition near −150°C was observed, but the points, Fig. 1, appear to deviate from a smooth curve between −120° and −160°C.

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Crystal Structure: The structure of wrought chromium was investigated by the powder method in a Debye-type camera. The specimen consisted of powder filings cleaned magnetically and annealed 2 hr at 800°C in vacuum. At −190°C, chromium was found to have the same structure as at room temperature, body-centered cubic.

The lattice constants of the powder specimen were measured between −2° and 58°C in a back-reflection focusing camera.[9] A current of either cooled or warmed helium controlled sample temperature. Chromium $K\alpha_1$, α_2, and β (211) reflections (Siegbahn 1931) corrected for refraction[10] and systematic errors[11] were used. The precision of individual determinations is 0.003 pct. The lattice constants in Angström units[11] (10^{-8} cm) are plotted in Fig. 2 (inset).

The lattice constants calculated from 0°C using the thermal expansivity are shown by the dashed curve Fig. 2 (inset). The differences between the observed and calculated values, although small, appear significant and will be discussed.

Thermal Emf and Thermoelectric Power: The thermal emf of the chromium (electroformed)-platinum couple was measured between −200° and 103°C with the reference junction at 0°C. In the results, Fig. 3, a positive emf signifies positive current is passing from platinum to chromium at their variable-temperature junction. The slope of the thermal emf curve (thermoelectric power) shows an abrupt change at 40°C, Fig. 3.

Paramagnetic Susceptibility: The paramagnetic susceptibilities of an electroformed chromium tube and unannealed electrolytic chromium powder were measured at a series of temperatures, Fig. 4, by F. J. Morin. In the method, the pull of an electromagnet of known field gradient on the sample was measured with an analytical balance. The maximum flux density in the field was 5000 gauss. Spectrochemical analyses of the samples gave no trace of ferromagnetic impurities. The powder sample, however, was visibly oxidized.

The results for the two samples, shown in Fig. 4, disclose no evidence for transitions near either −152° or +37°C. (The spread among the points can be reasonably ascribed to experimental error.) The different slopes appear to be connected with the sample purity—the higher purity material has the larger positive susceptibility coefficient. Söchtig's values for electrolytic chromium powder of unstated purity agree closely with those obtained in this investigation for similar powder.

Nature of the Transitions

From the four curves of Fig. 1, a good deal can be concluded about the transition near room temperature. It takes place over a large temperature range, progresses only as temperature is changing, within the experiment is independent of the rate of heating and cooling, and is reversible with no hysteresis being detected. (After heating the electroformed sample to 207°C, a stable modulus-temperature curve was obtained, Fig. 1.) On heating, the transition (Fig. 1) begins at approximately −20°C, increases in intensity to a critical value near 37°C, but is not complete until approximately 140°C.

Evidence for the transition near −150°C has been observed only in Young's modulus, Fig. 1. The modulus effect, taking place between −160° and −120°C with a critical temperature at −152°C, is

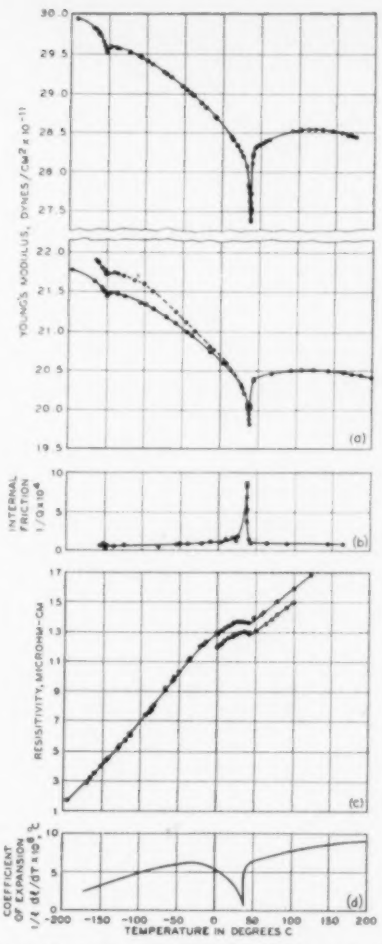

Fig. 1—Thermal dependence of some properties of chromium.

a. **Young's Modulus** ($1 \frac{\text{dyne}}{\text{cm}^2} = 1.4504 \times 10^{-5} \frac{\text{lb}}{\text{in.}^2}$).
Upper curve, wrought electrolytic sample.
Lower curve, electroformed sample.
Dashed curve, before being heated to 207°C.

b. **Internal friction** (wrought electrolytic sample).

c. **Electrical resistivity.**
Upper curve, wrought electrolytic sample.
Lower curve, electroformed sample.

d. **Coefficient of expansion** (wrought electrolytic sample).

similar to the one near room temperature but is of much smaller magnitude.

These transitions in chromium occurring over a temperature range and without hysteresis are akin in pure metals to loss of ferromagnetism. Chromium, however, is not ferromagnetic. The small, almost constant paramagnetic susceptibility (Fig. 4) means that probably neither of the transitions are loss of antiferromagnetism.[12] The overlapping 4*s* and 3*d* bands in chromium suggests the transitions involve the ratio of 4*s* to 3*d* electrons. From the relative decrease in electrical resistance on heating through the transition near room temperature, Söchtig[2] postulated that the proportion of 4*s* to 3*d*

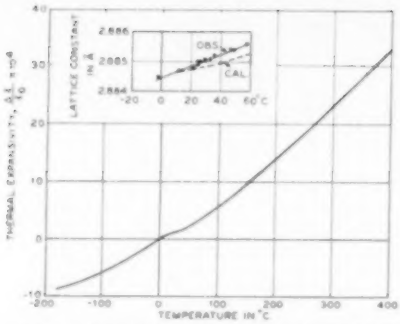

Fig. 2—Thermal expansivity and thermal dependence of lattice constant in wrought electrolytic chromium.

electrons, that is, the relative number of carriers, is increasing. The lack of hysteresis seems to require an electronic change of this kind. The temperature course of the transition would depend upon the electronic energy considerations determining the ratio of 3*d* to 4*s* electrons.

Referring to the transition near room temperature, the inflection in the expansivity curve, Fig. 2, is equivalent, on heating, to a decrease in sample length of approximately 2×10^{-4} in. per in. or, assuming isotropic expansion characteristics, a decrease in volume of 6×10^{-4} in.^{3} per in.^{3} Because of this volume effect, increasing the pressure would be expected to lower the transition temperature. This has been observed, for Bridgman[1] found that increasing the pressure from 0 to 4000 kg per cm^2 decreased the temperature of minimum resistivity from 12° to −20°C. The transition is also influenced by sample purity. In a number of impure samples Hidnert[13] observed a lower temperature range and a larger volume effect.

On heating through the transition, Young's modulus is larger than the value obtained by extrapolating from below the transition, Fig. 1*a*. The increase in modulus may be regarded as arising from a difference between the U (r) relations at high and low temperatures (the modulus is proportional to $\partial^2U/\partial r^2$). With increasing temperature the U (r) relation (as in loss of ferromagnetism[14]) gradually changes from that of the low-temperature "modification" to that of the high-temperature "modification." From this consideration alone the modulus is expected to increase gradually through the transition. The observed initial negative deviation of

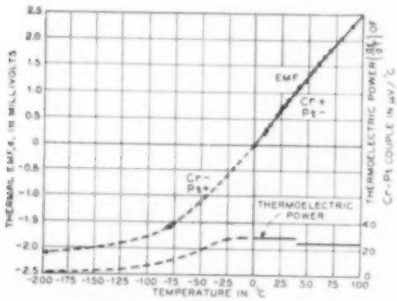

Fig. 3—Thermal emf and thermoelectric power of electroformed chromium (Cr-Pt couple).

Young's modulus from a usual temperature dependence, Fig. 1, implies an additional contribution to the strain. The additional strain may arise as follows: On heating through the transition there is a negative volume effect with the largest change in coefficient near the temperature of minimum modulus (37°C). The additional strain like this volume effect (compare Figs. 1*a* and *d*) increases with temperature to 37°C then abruptly decreases. In this temperature region the ratio of the two "modifications" or the completeness of the transition may well be stress-dependent. A tensile stress will then cause the transition to progress in that direction which increases the volume (toward the low-temperature "modification") and the opposite will hold for a compressive stress. The resulting volume changes give larger tensile and compressive strains. The increased internal friction at 37°C, Fig. 1*b*, is further evidence for a mechanism of this sort.

The difference between the observed lattice constants and those calculated from the expansion data (Fig. 2) suggests the transition involves a departure from the ideal body-centered cubic arrangement. Direct evidence of this departure has not been observed. The difference corresponds to 0.04 pct more atoms (on the average) associated with a unit cell

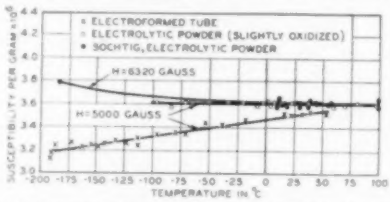

Fig. 4—Paramagnetic susceptibility of electrolytic chromium.

above the transition than below and an equal decrease in the proportion of unit cells. The denser packing is consistent with the observed overall increase in Young's modulus on heating through the transition. The extra atoms by short range movements perhaps assume interstitial (face-centered) positions giving the denser packing. Alternatively, denser packing could arise from disappearance of vacant lattice sites on heating.

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Effect of Heat Treatment on the Electrical Properties of Germanium

by H. C. Theuerer and J. H. Scaff

Germanium may be reversibly converted from n to p type by heat treatment. Data for the conversion and the associated changes in resistivity are given and the results are interpreted in terms of changes in the donor-acceptor balance.

MEANS for controlling the electrical properties of germanium in a predictable manner are of interest because of the increasing utilization of this element as the semiconducting material in electrical devices. Since both the mechanism and the magnitude of the electrical conductivity depend upon the kind and quantity of impurities present, the conductivity usually is adjusted by first carefully purifying the germanium, and then, by standard alloying procedures, adding the elements desired. The elements usually added are from the third or fifth periodic groups depending upon whether p- or n-type germanium is desired. However, in the development of germanium rectifiers during the war, it was found that it was possible also to modify reversibly the conductivity of germanium and even to produce conversion from n to p type by heat treatment.[1,2] Since then a detailed study of this effect has been made. The data are presented in this paper and an explanation is offered for the effects observed.

Preparation and Experimental Procedure

The method used in preparing the germanium ingots for this investigation has been previously described.[2] The method consists essentially of (1) reduction of GeO_2* and (2) preparation of a 50-g ingot from the reduced material. Graphite containers are used in both steps. In the first step the GeO_2 is reduced in hydrogen at 650°C to form a sponge germanium which, to assure complete reduction and to obtain massive materials, is fused subsequently in the reduction furnace by gradually raising the temperature to 1000°C. The button of germanium thus obtained corresponds to a yield of 99.8 pct. The final ingot is prepared by fusion of the germanium button in a helium atmosphere. A cylindrical crucible in a vertical silica tube furnace is employed and the crucible is heated by an external induction coil. The ingot is solidified from the bottom upward by raising the induction coil at a constant rate with power to the coil kept at a fixed value.

In such ingots, segregation is normal and most of the impurities are concentrated in the last region of the ingot to freeze. It follows then that the major portion of the ingot is purer than it would have been if freezing had occurred in a random fashion. Moreover the orderly advance of the freezing surface during solidification establishes in the ingot a succession of surfaces of constant composition, if it is assumed that the liquid is homogeneous and that diffusion in the solid is negligible. Therefore, some information on the distribution of impurities in the ingot may be acquired by determining the shape of the solid-liquid interface at different stages of solidification. This is of importance because the concentration of impurities will be seen to affect the response of germanium to heat treatment. Such information is difficult to acquire by direct means, for the impurities responsible for the electrical properties of germanium prepared in this way are present

* Rectifier grade, prepared by hydrolysis of redistilled $GeCl_4$. Obtained from the Eagle Picher Co.

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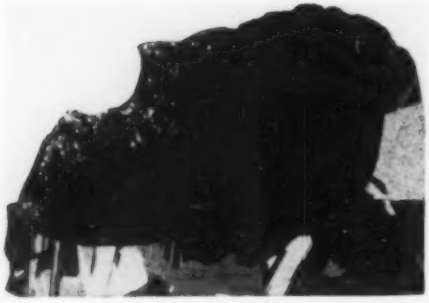

Fig. 1—Shape of solid-liquid interface during the solidification of a germanium ingot.
a (above)—Initial stage.
b (right)—After ingot is half solidified.

to the extent of only a few parts in ten million and are thus beyond the range of the usual methods of analysis.

The shape of the solid-liquid interface may be determined by preparing ingots in the standard way except that after allowing solidification to proceed for the desired time the crucible is upset to allow the remaining liquid to flow out quickly. Sections of such ingots, etched to reveal the grain structure, are shown in Fig. 1. It will be noted from these that the freezing surfaces are quite smooth and regular and that there is no sign of dendrite growth. Also it may be seen that, while solidification occurs predominately from the bottom of the crucible upwards, there is sufficient heat loss from the sides of the crucible that solidification occurs to some extent from the sides of the crucible inward. This accounts for the curvature in the solid-liquid interface.

For the heat-treating studies the 50-g ingots were cut in half through the vertical axis and from the central portion of one half of the ingot a rectangular specimen $\frac{1}{8}$x$\frac{1}{8}$x1 in. was cut, so that the long axis of the specimen was approximately parallel to the vertical axis of the ingot. This specimen was used for resistivity measurements by a potentiometric method. The remaining half of the ingot was used for rectification measurements. To prepare the ingot for these measurements, a large area electroplated contact was made to the rounded surface of the ingot. The cut face of the ingot was then ground flat with abrasive, etched and the surface explored with a tungsten point under a controlled load. By measuring the current through the contact when the direction and magnitude of the applied voltage was changed, it was possible to differentiate quickly between *n*- and *p*-type germanium. Typical rectification patterns obtained in these tests are shown in Fig. 2.

The rectification pattern of Fig. 2 for *n*-type germanium is typical of that of a "high back" voltage rectifier. It will be noted that in the reverse direction (Ge positive with respect to the point) little current flows even at voltages as high as 50v. With increasing applied voltage, larger currents flow and a value is finally reached where further increases in voltage result in a reduced potential drop across the rectifying junction. The peak voltage which the junction will support is one way of characterizing the properties of germanium as will be seen in the following section.

The half section of the ingot and the companion resistivity specimen prepared as described were heated at successively higher temperatures between 500° and 900°C for periods of 24 hr in a quartz tube in which a helium atmosphere was maintained. After each treatment the specimens were rapidly cooled to room temperature by removing the quartz tube from the furnace and allowing it to cool in still air. The surfaces of the specimens then were ground and etched prior to measurement of the conductivity type and resistivity. At several of the temperatures after the initial 24-hr treatment, the specimens were reheated for an additional 48 hr and the conductivity type and resistivity were remeasured. No significant changes were observed as a result of the second treatment, indicating that a steady state is reached at these temperatures in a 24-hr period. After the samples had been treated at 900°C, they were reheated at several lower temperatures between 900° and 400°C for 24 hr each, again measuring the properties after each heat treatment.

Effect of Heat Treatment on Conductivity

In the as-cast state the germanium ingots are *n* type throughout with peak reverse voltages ranging between 50 and 200 v depending on position in the ingot. This is illustrated schematically for ingot sections in Fig. 3, in which the contour lines show regions in the ingot which have the peak reverse voltages listed. The similarity in shape between the contours of peak reverse voltage and the contours of the freezing surface at different stages in solidification, given in Fig. 1, is at once apparent. The peak reverse voltage is highest near the bottom of the ingot and lowest near the top of the ingot. From this it is evident that the peak reverse voltage of the germanium is systematically related to its purity.[2]

If the germanium ingot is heat treated at temperatures above 550°C and cooled to room temperature, in the manner previously described, part of

the ingot transforms to p-type germanium. Such material has a poor rectification characteristic with tungsten points, and does not support high voltages in either direction. The regions of the ingot which transform from *n* to *p* type as a result of the various heat treatments and the peak-voltage contour lines for the untransformed *n*-type regions are also given in Fig. 3. It should be recalled that, because of the solidification procedure used in preparing the ingots, the purity decreases progressively from bottom to the top of the ingot. The data of Fig. 3 show that the purer material in the ingot converts to *p* type at the lowest temperature of treatment. Higher temperatures of treatment are required to convert those regions in the ingot of lower purity. The general curvature of the *n/p* boundaries after heat treatment suggests again that these are regions of equal purity formed during the freezing process. It will be noted that even at temperatures as high as 900°C, the impurity-rich top of the ingot is not converted to *p* type.

The thermal conversion of germanium from *n* to p type is completely reversible. Fig. 3 shows, for example, that the amount of *p* material in the ingot and the peak-voltage contours are the same after a 600°C treatment, whether or not the sample had previous high-temperature treatments. Also, although the specimen had been treated for a total of 96 hr, a final heat treatment at 500°C resulted in material having the same characteristics as that after the initial 500°C treatment. This would not be expected if a substantial diffusion of the impurities initially in the ingot had occurred during the course of the treatments.

Large changes in resistivity are also produced by the heat treatment. Resistivity data for materials from three positions in an ingot are given in Fig. 4. Several features of the curves are to be noted. The resistivity is highest for the purer material at the bottom of the ingot and lowest at the top. As the temperature of treatment increases, resistivity rises reaching a maximum at the *n/p* conversion point. For higher temperatures of treatment the resistivity falls rapidly and reaches a relatively low value after treatment at 900°C. The divergence in the three curves tends to decrease for the higher temperatures of treatment. The resistivity after treatments between 500° and 900°C is independent of previous thermal history and depends only on the final temperature of treatment and on the location of the material in the ingot. Finally the transition temperature for *n/p* conversion increases as the impurity level increases.

Other experiments had shown that the resistivity had reached a constant value after treatment at 500°C for 24 hr. For lower temperatures of treatment, the changes occur much more slowly as shown by data for treatments for various periods of time at 360° and 400°C. For both series of measurements the specimens were first heated to 900°C for 24 hr and rapidly cooled to obtain *p* germanium. They were then reheated at 369° or 400°C for different intervals of time, cooled to room temperature, and measured. These data are given in Table I and in Figs. 5 and 6.

With increasing time of treatment at 360°, a gradual increase in resistivity is observed and after 1084 hr of treatment the upper third of the specimen transformed to *n* type. At 400°C the material is converted to *n* germanium after 24 hr. At this temperature about 500 hr are required for resistivity to

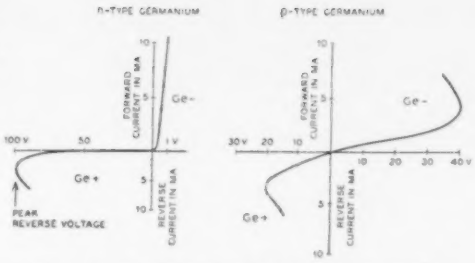

Fig. 2—Typical rectification patterns for n and p germanium with tungsten point contacts.

reach a constant value. It is to be noted that the terminal values of resistivity after treatment for 1000 hr at 400° are the same as those obtained initially after treatment at 500°C for 24 hr.

Proposed Mechanism for the Effect of Heat Treatment

It is now well established for both silicon and germanium that p-type or *n*-type conduction results if impurities from the third (acceptors) or fifth (donors) periodic groups respectively are present.[5] The conductivity at room temperature is proportional to the number of impurity atoms present. *P*-type conductivity may also result from acceptor levels introduced by lattice defects produced, for example, by physical displacement of germanium atoms from their normal lattice sites.[4] Moreover if donor and acceptor levels occur simultaneously, a compensating action occurs so that the mechanism and magnitude of conductivity depends upon which carrier is in excess and on its net concentration. It is apparent, therefore, that the changes in the properties of germanium on heat treatment are due to a change in the donor-acceptor balance. If we assume, for example, that the concentration of acceptors depends upon the temperature of heat treatment, then for *n*-type material, as the temperature of heat treatment is increased, the acceptor concentration rises and the net donor concentration falls so that an increase in resistivity is observed. The resistivity reaches a maximum after treatment at

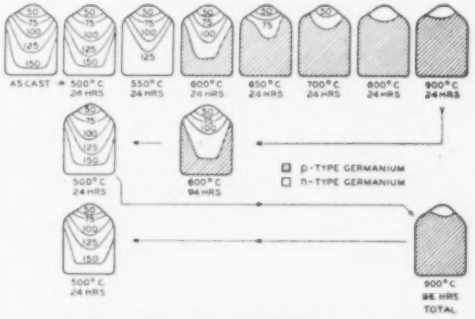

Fig. 3—Effect of different heat treatments on the conductivity type of germanium.

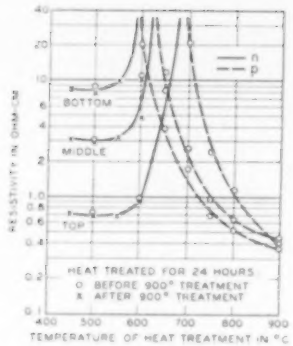

Fig. 4—Effect of temperature of treatment on the resistivity of germanium from different positions in an ingot.

the temperature where the donors and acceptors just balance or compensate one another. For treatments above this temperature acceptors are in excess and the material is p type, and, since the acceptor concentration continues to increase with increasing temperature of heat treatment, the resistivity accordingly decreases. This hypothesis adequately explains the shape of the curves of Fig. 4 and the same argument may be used to explain the curves of Fig. 6. Following the argument further it would be expected that the temperature of conversion from n to p type would be lowest for material with the lowest initial concentration of donors. This is actually the case as shown by the curves of Fig. 4. This also explains the variation in resistivity with location found in ingots heat treated so that the lower part is p type and the upper part n type (e.g., the 600° treatment, Fig. 3). In this case the resistivity of the p-type material is low at the bottom of the ingot and increases as the p/n boundary is approached. The resistivity then falls as the top of the ingot is approached. It is believed that treatment at 600°C increases the acceptor concentration uniformly in the ingot just enough to convert the bottom portion of the ingot to p type. In this region of the ingot the concentration of acceptors must exceed that of the donors. Since, however, the donor concentration increases with height in the ingot, the excess of acceptors over donors in the p region decreases with height. Hence the resistivity rises in this region as the p/n boundary is approached. Above the boundary, the donor concentration exceeds that of the acceptors and in this region the concentration of donors in excess of the acceptors increases progressively with height in the ingot. The resistivity accordingly decreases with height in the n region.

The essential feature of the above explanation is that the number of acceptor levels or "holes" depend upon heat treatment. Two mechanisms by which this could occur are known. In the one mechanism, essentially chemical in nature, heat treatment is supposed to change the effective concentration of acceptor impurities as, for example, by a change in solubility with temperature. The other mechanism is essentially physical in nature. It has been shown[1] that bombardment of germanium by nucleons converts n germanium to p type and that the converted material may be transformed to the original n type by heat treatment at low temperatures. The bombardment is supposed to break the valence bonds by displacement of atoms in the lattice to form defects or "holes" which compensate the existing donors and ultimately result in conversion to p type. Beyond the conversion point further bombardment introduces additional defects which further increase the conductivity. According to this view, heat treatment at low temperatures, of the order of 500°C, allows these defects to be "healed" with reversion to the original properties. If the defects created by heating the germanium to temperatures above 500° are retained on cooling to room temperature, then this physical mechanism would also account for the results of the present investigation. Additional experiments are required to determine which of these mechanisms is correct.

Table I. Effect of Heat Treatment at 360°C on the Resistivity of p-type Germanium Obtained by Thermal Conversion at 900°C

Time at 360°C, Hr	Resistivity at Locations in Ingot Indicated		
	Top, Ohm-cm	Middle, Ohm-cm	Bottom, Ohm-cm
0	0.56	0.50	0.33
24	0.65	0.73	0.45
114	1.05	1.25	0.72
330	2.35	3.96	2.00
1,084	1.54*	6.88*	11.56

* Material converted to n type.

Fig. 5—Effect of heat treatment at 400°C on the conductivity type and peak reverse voltage of thermally converted p-type germanium.

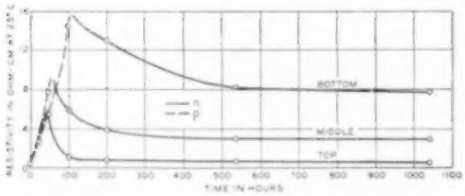

Fig. 6—Effect of heat treatment at 400°C on the resistivity of thermally converted p-type germanium from different positions in the ingot.

Summary

It has been shown that germanium may be reversibly converted from n to p type with accompanying changes in resistivity by appropriate heat treatment. The results have been interpreted in terms of changes in the balance between acceptors and donors resulting from an increase in acceptor

levels as the temperature of heat treatment is increased.

Two mechanisms for the increase in acceptor concentration have been given, one postulating a change in solubility of an acceptor impurity, the other postulating the formation of acceptor centers by thermally produced lattice defects.

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Technical Note

Grain Boundary Effect In Surface Tension Measurement

by Harry Udin

IN 1948, the writer and his associates determined the surface tension of solid copper by balancing the force of surface tension in a very fine wire against an external load.[1] At that time we, in common with other early workers, assumed that grain boundary energy in a pure metal is very small in comparison to the energy of an external surface. Accordingly, we neglected the internal surface energy of the coarse-grained specimens.

Since that time, experimental evidence has accumulated showing that grain boundary energy, far from being small, is generally about one-third of the energy of an external surface.[2-4] This is sufficient to introduce a significant error into our determination. The differential equation governing equilibrium is:

$$wdl = \gamma ds_e + \gamma^\circ ds_i \qquad [1]$$

rather than

$$wdl = \gamma ds$$

as originally written. w is the balancing force in dynes, l the length of the specimen, s_e the external and s_i the internal surface area, γ the copper/copper vapor surface tension, and γ° the grain boundary tension.

Fortunately, we had made for another purpose a careful study of the size and shape of the grains, and found that the boundaries, with rare exceptions, traversed the specimens and were perpendicular to the wire axis. For this case, eq 1 leads to

$$w = \pi r\gamma - \left(\frac{n}{l}\right)\pi r^2\gamma^\circ \qquad [2]$$

where r is the wire radius and $\left(\frac{n}{l}\right)$ is the number of grains per unit length. A count of some twenty 5-mil wires indicated that $\frac{n}{l}$ became 80 ± 10 after a short anneal near the melting point, and remained nearly constant for as long as 96 hr at temperature.

An assumption of $\gamma^\circ = 1/3\gamma$ leads to a defining equation for γ:

$$w = \pi r\gamma \left[1 - \left(\frac{n}{l}\right)\left(\frac{r}{3}\right)\right] \qquad [3]$$

The term in the brackets may be considered a correction factor applied to eq 11 of ref. 1. Upon applying this factor, the surface tension of solid copper at its melting point is found to be 1650 ± 100 dynes per cm, rather than 1370 as previously reported.[1] The new temperature coefficient is −0.55 dynes per cm per °C.

Grain boundary energy is more significant than surface energy to the physical metallurgist. It is evident from eq 2 that a series of experiments with wires of different grain size can lead to an evaluation of γ°. The details of such an experiment are being worked out now.

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TN 51 E. Manuscript, Nov. 9, 1950.

Crystallographic Angles For Magnesium, Zinc and Cadmium

by Edward I. Salkovitz

THE determination of the orientation of metal single crystals and the studies of plastic deformation are greatly facilitated by the use of the stereographic projection. To draw a standard projection of the crystal it is necessary to have a tabulation of the angles between the various crystallographic planes of the particular crystal studied. Bozorth[1] has published such a table for the cubic system which can be found in many reference books; such convenient tabulation for the hexagonal metals, however, does not appear to be in the literature, although scores of workers have calculated these angles. Therefore, Table I of angles for magnesium, zinc, and cadmium has been compiled. Since the c/a ratio is different for each of these metals, three separate calculations are necessary.

Table I. Angles Between the Crystallographic Planes in Close-Packed Hexagonal Crystals of Magnesium, Zinc, and Cadmium

HKIL	*hkil*	Magnesium (c/a = 1.6233)		Zinc (c/a = 1.8563)		Cadmium (c/a = 1.8859)	
0001	$10\bar{1}8$	13°	11.3′	15°	0.0′	15°	13.6′
	$10\bar{1}7$	14°	59.6′	17°	1.5′	17°	16.8′
	$10\bar{1}6$	17°	33.5′	19°	39.5′	19°	56.8′
	$10\bar{1}5$	20°	33.2′	23°	12.3′	23°	32.1′
	$10\bar{1}4$	25°	6.7′	28°	16.6′	28°	33.8′
	$20\bar{2}7$	28°	10.5′	31°	29.0′	31°	53.3′
	$10\bar{1}3$	32°	0.1′	35°	32.7′	35°	58.5′
	$20\bar{2}5$	36°	51.1′	41°	24.6′	41°	3.4′
	$10\bar{1}2$	43°	8.9′	46°	59.0′	47°	26.1′
	$20\bar{2}3$	51°	30.0′	55°	1.0′	56°	12.8′
	$10\bar{1}1$	61°	55.6′	64°	59.5′	65°	20.1′
	$20\bar{2}1$	75°	4.0′	76°	52.2′	77°	4.1′
	$10\bar{1}0$	90°	0.0′	90°	0.0′	90°	0.0′
	$21\bar{3}2$	68°	2.4′	70°	37.1′	70°	51.4′
	$21\bar{3}1$	78°	36.9′	79°	59.8′	80°	9.2′
	$21\bar{3}0$	90°	0.0′	90°	0.0′	90°	0.0′
	$11\bar{2}8$	22°	5.3′	24°	53.7′	25°	14.5′
	$11\bar{2}6$	28°	25.3′	31°	44.9′	32°	9.3′
	$11\bar{2}4$	39°	4.2′	42°	51.7′	43°	19.1′
	$11\bar{2}2$	58°	22.2′	61°	41.3′	62°	3.9′
	$11\bar{2}0$	90°	0.0′	90°	0.0′	90°	0.0′
	$12\bar{3}2$	68°	2.4′	70°	37.1′	70°	51.4′
	$12\bar{3}1$	78°	36.1′	79°	59.6′	80°	9.2′
	$12\bar{3}0$	90°	0.0′	90°	0.0′	90°	0.0′
1010	$21\bar{3}0$	19°	6.4′	19°	6.4′	19°	6.4′
	$11\bar{2}0$	30°	0.0′	30°	0.0′	30°	0.0′
	$12\bar{3}0$	40°	53.6′	40°	53.6′	40°	53.6′
	$01\bar{1}0$	60°	0.0′	60°	0.0′	60°	0.0′

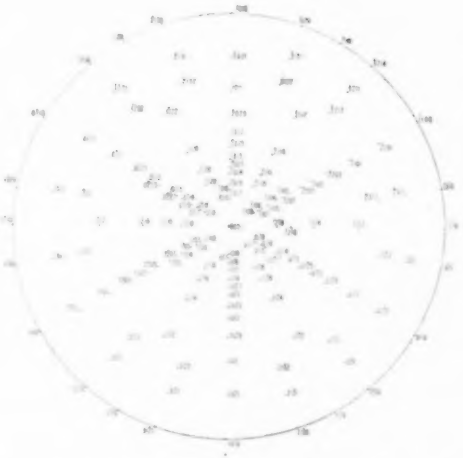

Fig. 1—Standard (0001) projection for zinc hexagonal $c/a = 1.856$.

The angles ϕ between $(HKIL)$ and $(hkil)$ were calculated by means of the formula:

$$\cos\phi = \frac{Hh + Kk + \frac{1}{2}(Hk + hK) + \frac{3}{4}\frac{a^2}{c^2}Ll}{\left[\left(H^2 + K^2 + HK + \frac{3}{4}\frac{a^2}{c^2}L^2\right)\left(h^2 + k^2 + hk + \frac{3}{4}\frac{a^2}{c^2}l^2\right)\right]^{1/2}}$$

The c/a ratios were calculated from data given in the 1948 edition of Metals Handbook. Fig. 1 is a typical (0001) standard projection of zinc. For all practical purposes, it serves for cadmium as well, as can be seen from the table. For magnesium, however, it is necessary to construct another net.

[1] R. M. Bozorth: *Physical Review*, (1925) **26**, 390.

EDWARD I. SALKOVITZ is on the staff of the U. S. Naval Research Laboratory of the Office of Naval Research, Washington, D. C.

TN 50 E. Manuscript, Oct. 10, 1950. Part of these calculations were made at Carnegie Institute of Technology.

AIME OFFICERS

Donald H. McLaughlin, President

Vice Presidents

R. W. Thomas A. B. Kinsel C. V. Millikan

C. H. Benedict Philip Kraft

Vice-President and Treasurer

Andrew Fletcher

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E. H. Roble, Secretary

E. J. Kennedy, Jr., Asst. Secy. Ernest Kirkendall, Asst. Secy.

H. N. Appleton, Asst. to Secy. H. A. Maloney, Asst. Treas.

AIME Publications Program And Policies Established for 1951

Pursuant to Article X of the bylaws of the AIME, the following information is hereby given as to the *"conditions, prices, and terms under which the various classes of members, and Student Associates, severally, shall be privileged to obtain publications of the Institute during the ensuing year."*

Publications authorized for 1951 publication include the following: MINING ENGINEERING, published monthly, contains news and technical papers of interest to those engaged in exploration, mining geology and geophysics, and in metal, nonmetallic, and coal mining and beneficiation, and fuel technology. The JOURNAL OF METALS, published monthly, contains news and technical material of interest to those engaged in nonferrous smelting and refining, iron and steel production, and physical metallurgy. JOURNAL OF PETROLEUM TECHNOLOGY, published monthly in Dallas, contains news and technical articles for those engaged in petroleum production.

A subscription for any one of the journals will be supplied to all members in good standing without further charge. A member ceases to be in good standing if current dues are not paid by Apr. 1. If more than one of the monthly journals is requested, $4 extra will be charged for an annual subscription, or 75c per single copies. Higher prices may be charged for special issues. The nonmember subscription price for each journal is $8 in the Americas; foreign, $9. Student Associates who pay dues of $4.50 will be entitled to the same privileges for all publications as members except as noted. Those who pay $2 will not receive subscriptions to the journals but otherwise have the same privileges.

Three volumes of Transactions are authorized for 1951 publication as follows: No. 187, Mining Branch; No. 188, Metals Branch; and No. 189, Petroleum Branch. These volumes will be available to members at $3.50 each for a first copy if paid for in advance with dues; otherwise at the nonmember rate of $7, less 30 pct. Nonmembers, $7 in the United States; foreign, $7.50.

Special volumes now planned for publication in 1951 include the following: (1) *Open Hearth Proceedings:* Price: AIME members, $7, and nonmembers, $10. (2) *Blast Furnace, Coke Oven, and Raw Materials Proceedings:* AIME members, $7 and nonmembers, $10. (3) *Electric Furnace Steel Proceedings:* AIME members, $7 and nonmembers, $10. (4) *Symposium on Tube Production Practice:* Price to be set. (5) *Basic Open Hearth Steelmaking:* second edition. Price to be set. (6) *Statistics of Oil and Gas Development and Production:* Covering data for year 1949. AIME members $3; nonmembers $6. (7) *Petroleum Conservation,* by Stuart Buckley. Price to be determined. (8) *Symposium on Solidification of Metals and Alloys.* Price to be set.

If dues are paid subsequent to Jan. 31, back issues of Institute journals will be supplied only if adequate stocks are on hand. A member may not receive a volume of Transactions or a special volume in lieu of a monthly journal. Members in arrears for dues are not entitled to special members' prices for publications.

Rocky Mountain members may have their choice of a subscription to one of the journals on request.

Annual Meeting Program Nears Completion

There have been a few minor changes and additions in the program of the Metals Branch printed in the December issue of the JOURNAL OF METALS. The Iron & Steel Div. will hold sessions on sulphur Monday morning and afternoon and Tuesday morning and afternoon. The Tuesday morning session on sulphur will be followed by the Howe Memorial Lecture. On Wednesday morning there will be a short session, preceding the Institute of Metals Div. Annual Lecture. A joint meeting with the Southwestern Open Hearth Section will be held at the Lenox Hotel Wednesday afternoon followed by a dinner to which Iron & Steel Div. members are invited. A technical session will be held on Thursday morning followed by the Iron & Steel Div. Executive Committee luncheon meeting. The Iron & Steel Div. Executive Committee will meet Thursday noon. There will be a Physical Chemistry of Steelmaking Committee luncheon meeting on Wednesday noon. The Metals Branch Council will meet Monday at 10 am.

The Institute of Metals Div. annual business meeting will be at 10:45 am, Wednesday, Feb. 21 in the ballroom of the Statler Hotel. Either a panel discussion or a seminar is scheduled tentatively for Monday. Powder Metallurgy sessions are scheduled for Thursday. One or two technical sessions are scheduled for each of the half days.

The Extractive Metallurgy Div. Monday morning session on Aluminum-Magnesium has been changed to the afternoon. On Wednesday, the morning and afternoon symposium on Electrolytic Zinc will close at 4:45 pm to be followed immediately by the Extractive Metallurgy Div.'s annual business meeting. Simultaneous with the Physical Chemistry session, a new EMD session has been scheduled jointly with the Minerals Beneficiation Div. for Thursday morning.

The Physical Chemistry of Nonferrous Extractive Metallurgy Committee will hold a symposium on Wednesday afternoon and all day Thursday.

H. S. Rogers Reelected ECPD President

Engineers Council for Professional Development held its annual meeting at the Tudor Arms Hotel, Cleveland, on Oct. 20-21. Harry S. Rogers, president of the Polytechnic Institute of Brooklyn, was reelected chairman of the Council, and L. F. Grant, field secretary of the Engineering Institute of Canada, vice-chairman. William N. Carey succeeds C. E. Davies as secretary, with Edward H. Robie as assistant secretary. C. E. Lawall, Curtis L. Wilson, and James R. Cudworth represent AIME on the Council. All were present at the Cleveland meeting, as were W. R. Chedsey, James L. Head, D. R. McKeithan, and L. E. Young, AIME.

The Committee on Student Selection and Guidance becomes the Guidance Committee, with W. F. Thompson as chairman; the Committee on Engineering Schools becomes the Education Committee, with S. C. Hollister continuing as chairman; the Committee on Professional Training becomes the Training Committee, with A. C. Monteith remaining chairman; the Committee on Professional Recognition becomes the Recognition Committee, R. H. Barclay continuing as chairman; the Committee on Engineering Ethics becomes the Ethics Committee, with William F. Ryan as chairman; the Information Committee continues, with Walter E. Jessup as chairman; and a new Student Development Committee has been set up to coordinate and administer relations between the engineering schools, the engineering societies, and industry, for the purpose of promoting the professional development of engineering students except as assumed by the Education Committee.

In the mineral industry field, the following curricula were reported as having been accredited for the first time in 1950: Geological Engineering—Arizona, Idaho, Minnesota, Pittsburgh, and South Dakota School of Mines. Mining Engineering, geology option—Missouri School of Mines. Metallurgical Engineering—Arizona and Wayne. Petroleum Engineering (petroleum and natural gas)—Texas College of Arts and Industries.

Among the reports presented at the meeting was that by the Committee on Training, of which Mr. Monteith is chairman, summarizing a two-year study on the first five years of professional development. The report was in six parts, discussing (1) orientation and training of the young engineer in industry; (2) the continued education of graduate engineers; (3) integrating the young engineer into his community; (4) registration of the young engineer; (5) self-appraisal methods for valuable characteristics in engineering; and (6) reading list and selected bibliographies.

A new record was made by ECPD in the prompt printing and distribution of its annual report, of 53 pages. This report, which contains among other things a complete list of accredited curricula in engineering schools and technical institutes, is available for 50c from the Secretary of ECPD, 29 W. 39th St., New York 18, N. Y., stamps acceptable.

ECPD is a joint organization sponsored by the four Founder Engineering Societies, plus the Engineering Institute of Canada, the American Society for Engineering Education, the AIChE, and the National Council of State Boards of Engineering Examiners, all of whom contributed $9480 to its income in the current year. Cash on hand and in bank at the end of the fiscal year ended Sept. 30, 1950 was $21,958, compared with $13,796 a year before. Principal items of income aside from the $9480 above noted were: fees for inspecting engineering schools, $19,243; sales of publications, $13,038; and grant from Engineering Foundation, $5000.

1951 AIME Officers And Directors Duly Elected

Officers and Directors of the AIME for 1951, to take office at the annual business meeting, Tuesday, Feb. 20, were declared duly elected at the Board meeting on Nov. 15. No candidates in opposition to those named by the Nominating Committee were offered. The new officers and Directors for 1951 thus are (as published in the July journals): W. M. Peirce, president; Joseph L. Gillson and Michael L. Haider, vice-presidents; Thomas G. Moore, Charles E. Lawall, John F. Myers, Fay W. Libbey, A. C. Rubel, and Leo F. Reinartz. The following Division Chairmen are Directors ex officio: Carroll A. Garner, A. B. Cummins, R. M. Brick, T. L. Joseph, Richard J. Lund, Allison Butts, Raymond E. Byler, Oliver C. Ralston, Richard W. French Jr., and the Chairman of the Mining, Geology, and Geophysics Div. who remains to be elected.

Student Associate Arrearages Eliminated

Several actions were taken by the AIME Board of Directors at its meeting on Nov. 15 that affect Student Associates. Instead of continuing Student Associates on the rolls after they become in arrears for dues, they will be dropped at the end of three months of delinquency. Thus, they can apply for reinstatement and change of membership grade at any future time without being penalized for any arrears in dues that may have been incurred. Where such arrears have been debited against a Student Associate, the sum of $1 is to be charged for reinstatement, regardless of the amount of accumulated arrears. Student Associates also are exempted from any registration fee at the forthcoming annual meeting in St. Louis, though they will receive the same technical papers as are distributed to those who pay the $5 or $8 registration fee. Students who are not Student Associates of the Institute will pay a registration fee of $1.

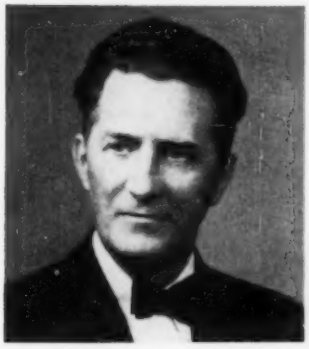
Metals Branch Dinner

The Metals Branch cocktail party and dinner will be held on Tuesday, February 20, at the Statler Hotel, St. Louis.

Change of Status Automatic For Junior Members on 33rd Birthday

Junior Members reaching the age of 33 are now required to change their status to Associate Member or Member. They are elected automatically to Associate Membership unless they apply for the higher professional grade, which requires six years of experience in the mineral industry, three years of which must be in positions of responsibility. To make transition as easy as possible in view of the requirement that an initiation fee be paid by either Associate Members or Members, the Board of Directors at its Nov. 15 meeting voted that the initiation fee for Junior Members so transferring be billed in four annual installments of $5 each. If such Junior Members are in arrears for dues, they may also pay such arrears in four annual installments.

Personals



Samuel L. Hoyt

H. K. Ihrig

Elmer Gammeter

Samuel L. Hoyt of Battelle Memorial Institute, Columbus, has been awarded the outstanding achievement medal of the University of Minnesota for his work on carbides and carbide cutting tools.

H. K. Ihrig has been elected vice-president in charge of research for Allis-Chalmers Mfg. Co., Milwaukee. He resigned as vice-president and director of laboratories of the Globe Steel Tubes Co. to accept this position.

Elmer Gammeter has been appointed director of laboratories for the Globe Steel Tubes Co., Milwaukee. Prior to this promotion he had been chief metallurgist.

Byron Zolin is now materials engineer for E. I. du Pont de Nemours & Co., Wilmington. He was plant metallurgist for Hotpoint, Inc., Chicago.

William Arthur Crowfoot has joined the Gildemeister, Meltzer, Ambor Cia. Ltd., Santiago, Chile. He was formerly connected with the Mine Safety Appliances Co., Lima, Peru.

George H. Thurston has joined the Benica Arsenal, Benica, Calif. as plant metallurgist. He was formerly connected with the ACF-Brill Motors Co., Hall-Scott Motor Div., Berkeley, Calif.

Simon E. Mayer is now employed by the Standard Telecommunication Laboratories, Enfield, Middlesex, England. He had been at Leeds University, Leeds.

Horace W. Potter is now in the open hearth department of the Lukens Steel Co., Coatesville, Pa. He transferred from Arthur G. McKee & Co., Cleveland, where he held the position of steel plant consultant.

William H. Clarke, development metallurgist for the Reynolds Metals Co., Sheffield, Ala., was recently transferred from Malvern, Ark. where he was junior metallurgist for the same company.

Francis C. Albers has been promoted to the position of chief metallurgist for the Chicago Pneumatic Tool Co. The concern has moved its Detroit manufacturing facilities to Utica, N. Y.

Robert Archer has been appointed to the research staff of the Lamp Div. of Westinghouse Electric Corp., Bloomfield, N. J., and will work on rare metals. He recently received his B.Met.E. degree from the Polytechnic Institute of Brooklyn.

Henry E. Warren, Jr. has been made a special representative for the Carnegie-U. S. Steel Co., Pittsburgh. He was formerly division superintendent of the open-hearth dept., Homestead Works.

Carl W. Westphal, technical representative of the Dorr Co. in South America, has returned to South America following a trip to the United States. He will be located temporarily in Lima, Peru, instead of his former headquarters in Buenos Aires, Argentina. On his return trip to Peru he spent two months visiting the concern's associated companies in England, France, Belgium, Germany, the Netherlands, Italy, and Switzerland.

Frank J. Smith has been elected vice-president in charge of iron ore operations of Oglebay, Norton & Co. He will continue with the same responsibilities he formerly had in his position of range manager.

Alexander Cochardt has obtained a year's contract from the Carnegie Institute of Technology, metals research laboratory as a research engineer.

William Pollack is presently employed as a product engineer with the Sylvania Electric Products Co., tungsten and chemical division, Towanda, Pa.

Oscar O. Miller has joined the International Nickel Co., Bayonne, N. J. as a research metallurgist. His work will involve research on hardenability of steel.

L. L. Wells, Jr. is assistant superintendent of the masonry dept. of South Works, U. S. Steel Co., (Carnegie-Illinois Steel Corp.), Chicago. He was formerly general supervisor of ceramic development.

Anton de Sales Brasunas, metallurgist from M.I.T., and **Richard J. Beaver,** associate metallurgist, University of Kentucky, have been appointed to the staff of the metallurgical div., Oak Ridge National Laboratory, operated by the Carbide & Carbon Chemicals Div., Union Carbide & Carbon Corp., Oak Ridge, Tenn. **Robert B. Neal, Jr.,** metallurgist, University of Kentucky has been appointed to the laboratory staff of the gaseous diffusion plant.

Joseph J. Becker is now research associate for the General Electric Co., research laboratory, Schenectady. He was formerly a teaching fellow at Harvard University.

Ethem T. Turkdogan has joined the British Oxygen Co., Ltd., London, as research metallurgist.

Amos A. Bradd is now employed by the Arcos Corp., Philadelphia, as an engineer. He formerly worked as supervisor of heat treatment for the Philadelphia Gear Works.

Obituaries

Frank A. Bond (Member 1942) died on July 3, 1950. Mr. Bond was born in Pittsburgh on Oct. 9, 1883 and attended public schools there. In 1913 he joined the Standard Chain Co., Pittsburgh, as general manager and remained with that concern until 1916. From 1916 to 1919 he was president of the National Chain Co., Marietta, Ohio. He became vice-president of the McKay Co., Pittsburgh, in 1919 and was with that company at the time of his death.

Willis H. Carrier (Member 1938), founder of the Carrier Corp., died on Oct. 7, 1950. Born in Angola, N. Y. on Nov. 26, 1876, Dr. Carrier attended Cornell University and graduated in 1901 with the degree of M.E. Following graduation he joined the Buffalo Forge Co. as a research engineer and in 1906 became chief engineer. While employed by this company his interest in air conditioning had its origin and he developed what was known as a spray-type air washer. In 1905 he devised a spray-type air conditioner capable of heating, cooling, humidifying air, an apparatus that provided the basis for those which are on the market today.

As a result of this work he formed the Carrier Engineering Corp., Newark, in 1915, which later was known as the Carrier Corp. Dr. Carrier served as president until 1931, becoming chairman of the board until 1943. In 1948 he was named chairman-emeritus. He presented a paper in 1911, which ranked as fundamental engineering doctrine and upon which was built the science of air conditioning. In the ensuing years he made numerous contributions to air conditioning.

NECROLOGY

Date Elected	Name	Date of Death
1950	C. P. Anderson	Unknown
1941	Lewis Edgar Garfield	Unknown
1917	John C. Gaul	October 23, 1950
1943	Irvin Gladstone	May 9, 1950
1921	Arthur Crandell Green	October 31, 1950
1945	Joseph John Haberthier	August 27, 1950
1947	John Robert Hallock	October 15, 1950
1937	George H. Harbordt	October 19, 1950
1913	Charles W. Johnston	October 24, 1950
1926	Virgil R. D. Kirkham	Unknown
1902	William B. McKinlay	October 21, 1950
1936	C. Quinby Schlereth	November 10, 1950
1921	Temple W. Tutwiler	September 9, 1950
1943	M. Harley Wilcox	March 1950
1900	Allen H. Woodward	November 26, 1950

Proposed for Membership

Metals Branch AIME

Total AIME membership on Oct. 31, 1950, was 16,896; in addition 4,161 Student Associates were enrolled.

ADMISSIONS COMMITTEE

E. C. Meagher, Chairman; Albert J. Phillips, Vice-Chairman; George B. Corless, H. P. Croft, Lloyd C. Gibson, Ivan A. Given, F. W. Hanson, T. D. Jones, P. Malozemoff, Richard D. Mollison, and John Sherman.

Institute members are urged to review this list as soon as the issue is received and immediately to wire the Secretary's office, night message collect, if objection is offered to the admission of any applicant. Details of the objection should follow by mail. The Institute desires to extend its privileges to every person to whom it can be of service but does not desire to admit persons unless they are qualified.

In the following list C/S means change of status; R, reinstatement; M, Member; J, Junior Member; AM, Associate Member; S, Student Associate.

Colorado
Golden—Sarkar, Satyabrata (J)

California
Los Angeles—Prussin, Simon A. (J) (R, C/S—S-J)
San Diego—Weity, John W. (M)
San Francisco—Valsamakis, Christopher (M)

Illinois
Caseyville—Dietz, William B. (J)
Chicago—Martin, Edward J. (J), Sherman, Russell G. (J) (C/S—S-J), Thomas, Harry J. (J)

Indiana
Hammond—Oravec, Joseph J. (J)

Maryland
Baltimore—Hughes, Stanley (M)
Dundalk—Ragan, Franklyn G. (M)

Massachusetts
Boston—Forsberg, Frank (M)
Cambridge—McMullin, John G. (J) (C/S—S-J)

Michigan
Negaunee—Beals, Rixford A. (J) (C/S—S-J)

Missouri
Kansas City—Reintjes, George P. (M)

New Jersey
Englewood—Winters, Ted S. (M)
Scotch Plains—Gayley, Harry B. (J) (C/S—S-J)

New York
Buffalo—Macdonald, Alexander J. (M)
New Rochelle—Boettner, Raymund C. (J) (C/S—S-J)
New York—Reis, Alfred J. (M), Boros, James K. (J) (C/S—S-J)
Port Washington—Balluffi, Robert W. (J) (C/S—S-J)

Ohio
Cincinnati—Swardson, Harold R. (A), Westermann, Fred E. (J) (C/S—S-J)
Columbus—Brittain, John O. (J) (C/S—S-J)
Jackson—MacMillan, James A. (M)

Pennsylvania
Apollo—Potkanowicz, Henry R. (J) (C/S—S-J)
New Kensington—Methe, Paul S. (J)
Philadelphia—Buratti, Ralph J. (J)
Pittsburgh—Dunn, Harold S. (M), Engstrom, Elmer R. (M), Giesey, Victor A. (A), Martini, A. James (J), Olleman, Rodger D. (J) (C/S—S-J)

Texas
Amarillo—Schultz, Kenneth H. (M)

Utah
Garfield—Ensign, Peter H. (M)
Salt Lake City—Richardson, Paul K. (M)

West Virginia
Glendale—Koenemund, Paul W. (M)

Brazil
E.F.C.B. Minas Gerais—Wscieklica, Janusz (J) (C/S—S-J)

Canada
Niagara Falls, Ontario—Pelletier, Robert C. M. (M)

France
La Roche de Rame (Houtes-Alpes)—Laroche, Andre P. (M)

Germany
Lauda (Baden)—Cochardt, Alexander W. (J) (C/S—S-J)

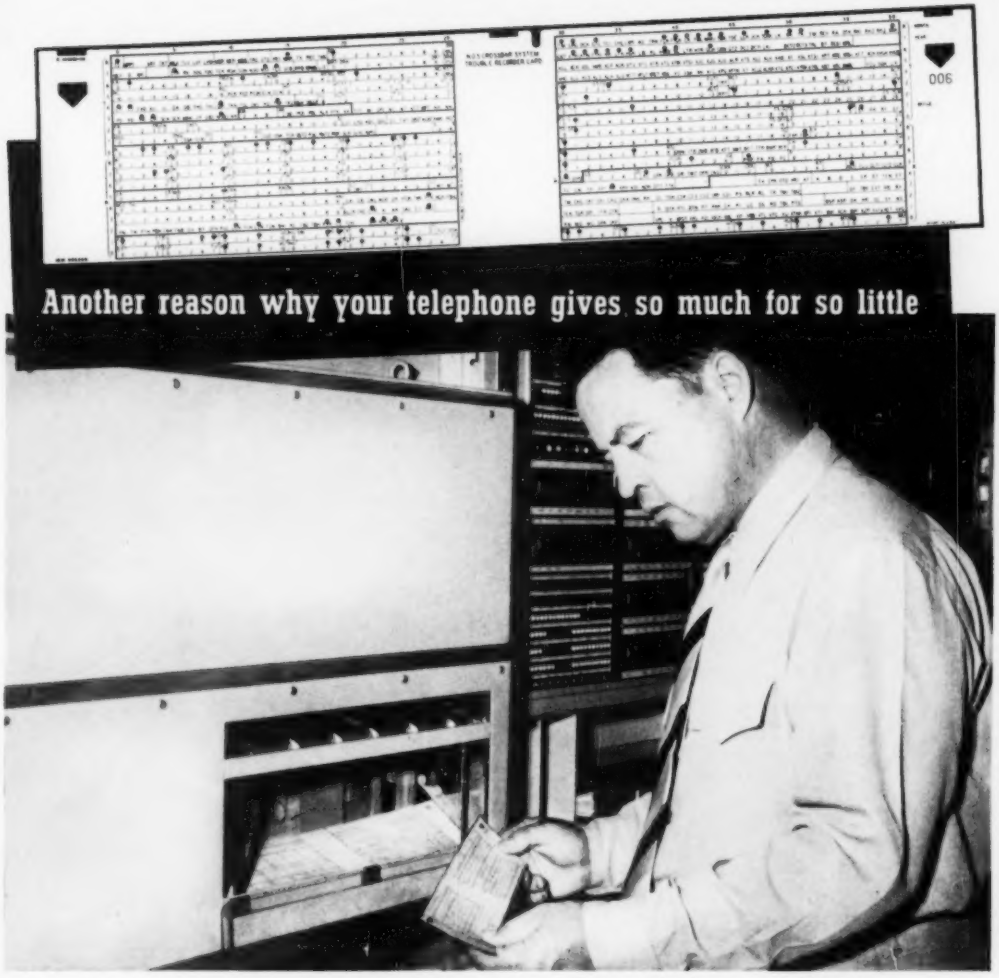
Southeast Africa
Johannesburg—Sprake, Patrick H. (M)

Dr. Zay Jeffries Elected Honorary Member

Zay Jeffries, a retired vice-president of the General Electric Co., Pittsfield, Mass., was elected to Honorary Membership in the AIME, on Nov. 15. This group is limited to 20 living members, and only 80 engineers and scientists have been so honored since the Institute was founded in 1871. With Dr. Jeffries' election, but one vacancy remains.

Dr. Jeffries has been prominent in metallurgical research in the diverse fields of theoretical metallurgy, aluminum alloys, and powder metallurgy. He also has been outstanding in administrating industrial research and development. His professional and administrative talents and efforts have made major contributions to the development of the tungsten filament lamp industry, to the establishment of the sintered carbide cutting tool, and to the development of new and improved industrial aluminum alloys.

He long has been a member, and a professionally active one, of AIME, having contributed many professional papers and participated actively in its metallurgical discussions for over 30 years. He has been both the Institute of Metals Annual Lecturer (1924) and the Iron and Steel Div., Howe Memorial Lecturer (1930); and in 1927 was the James Douglas Medalist. In 1936, he was awarded the John Fritz Medal, given by the four Founder Societies "for notable scientific or industrial achievement."



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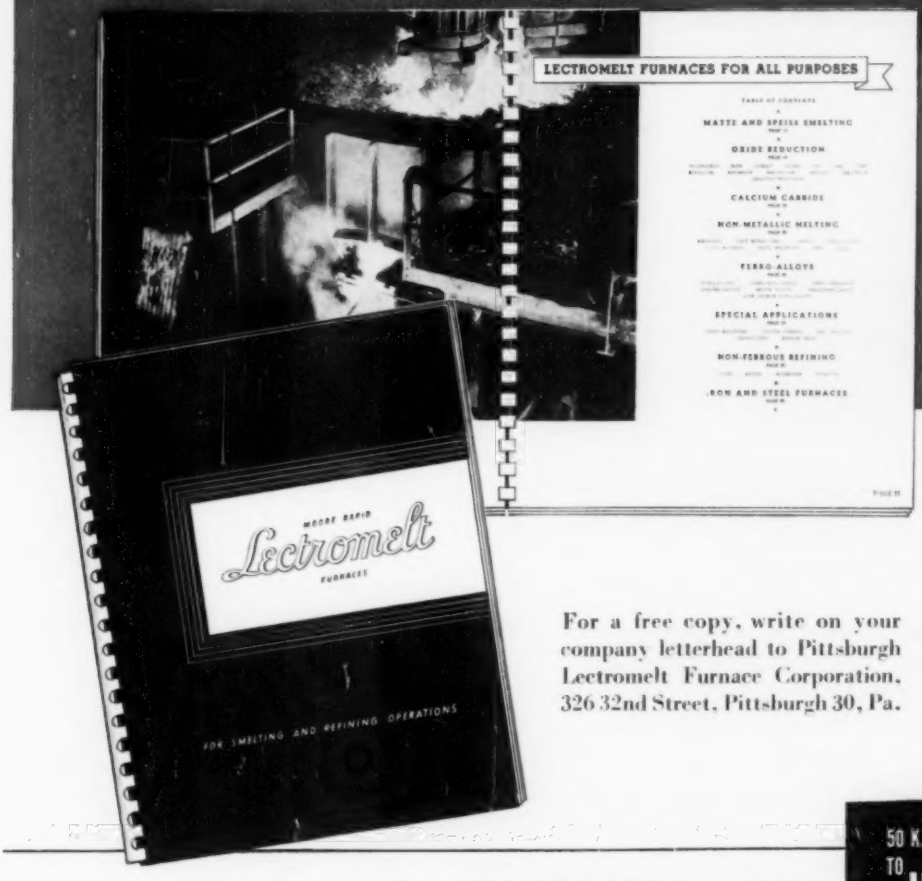

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